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1. Introduction

Production of oil from offshore California faces several obstacles because of the oil's relative viscosity and concentration of contaminants. The heavy offshore oil is less attractive to West Coast refiners than the higher grade Alaskan oil currently being sent to California. Most experts expect much of the offshore oil to be sent to Gulf Coast refineries that are better able to handle these poor quality crudes.[1/] Furthermore, given the more stringent pollution restrictions in California and current refinery economics, it is unlikely that refinery capacity in California will be upgraded to process significantly larger volumes of oil from the offshore discoveries.

The problem of producing and refining the oil, therefore, has centered around the best alternatives for transporting oil between California and the Gulf Coast. The most competitive transportation technologies involve the use of tankers or the construction of a pipeline. At the present time, California regulatory agencies favor the construction of pipelines, fearing the consequences of oil spills created by tanker accidents. Oil companies with reserves off the coast, on the other hand, generally favor the use of tankers to maximize their production flexibility and to reduce costs.

The debate about transportation has tended to focus on static comparisons between unit costs of transportation technologies. As is shown in this article, however, the constraint imposed on the possible production path by the choice of that technology may also be an important consideration. Most optimal depletion studies yield declining production paths over time, making the flexibility of the delivery system important. Because pipelines are designed to carry a relatively constant volume of production, this result suggests that the use of pipeline transportation systems could impose considerable constraints on the intertemporal flow of production relative to a more flexible system, such as the use of oil tankers.

The purpose of this article is to examine the conditions under which the optimal depletion path -- unconstrained by the transportation technology -- would yield a relatively constant production path that would fit naturally with a pipeline technology. Furthermore, using data from the California offshore oil situation, a set of simulations are conducted to observe the sensitivity of such a path to small perturbations in some of the model parameters.

Results of the simulation model indicate that conditions favoring the construction of a pipeline require highly restrictive assumptions about parameter values. In particular, minor changes in the assumed growth rate in oil prices quickly change a fairly flat production path into a steeply falling path. Values for cost function parameters and the degree to which California refineries increase their ability to handle heavier crudes are also shown to be important in the sensitivity experiments, especially with regard to the optimal size of such a pipeline. Preference for pipelines over a more flexible mode of transportation, therefore, may depend more on lower static unit costs in the pipeline case than would be the case with tankers, and the difference must be sufficiently large to offset the loss to producers caused by the resulting restructuring of the production path.

The theoretical model is presented in the next section. The model is cast in the framework of a price-taking producer that is a member of a competitive fringe. A simulation model for the offshore California case that builds on the theoretical model is then constructed in Section III. Simulation results for several sensitivity experiments are presented in Section IV, with concluding remarks in Section V.

II. The Theoretical Model

The problem of modeling the depletion of offshore oil from California can be cast in a relatively standard optimal depletion framework with the producer choosing a path of production that maximizes the present value of the resource stock. Until the resource is exhausted, decisions must be made regarding the quantity of output in successive time periods. The constraints faced by the producer have been outlined by Scott (1967). Specifically, unit extraction costs increase as reserves decrease, and the amount of production in any given time period is constrained by the producer's capital stock of wells, processing plants, and pipelines. A further complication introduced in this model is the coincident production of a substitute good, a resource of higher grade. Unlike simpler models (Herfindahl (1967) and Dasgupta and Heal (1974,1980)), sequential depletion of the different grades is allowed because of overlapping extraction cost schedules.

There are several other important modifications of the standard optimal depletion framework. First, the model developed below assumes that prices are determined exogenously. Standard optimal depletion models, such as those by Hnyilicza and Pindyck (1976), Salant (1976), Pindyck (1978), Lewis and Schmalensee (1980), and Eswaran and Lewis (1984), assume that prices are determined within the model as the result of the interaction of competitive or monopolistic forces. In this case, the agents modeled are considered part of the "competitive fringe," solving their depletion profiles based on price expectations. There is assumed to be minimal feedback from the actions of the fringe to the price-setters in the market. As a result, the model yields a production path that is based on the difference between the exogenously determined growth rate of prices and the firm's discount rate.

Second, the model is necessarily different in that the flow of the resource is characterized by a destination as well as a time period. There are two markets in which the resource can be sold with different costs of transportation associated with them. Because the price at each refinery is assumed to be the same for a given grade of crude oil, the profits per barrel of oil sold to the closer refinery, in this case California, are assumed to be higher than those associated with a barrel sold to the more distant refinery, Texas. Binding restrictions on the quantity that can be sold to California refineries at any point, however, lead to a trade-off between higher current transportation costs to reach the Texas market and the cost of postponing production until it can be sold in California.

The optimal depletion model can be described as follows:

$$(1) \quad \max_{q_2} \int_0^{\infty} e^{-\delta t} \left(P \cdot (q_1+q_2) - C(R,q_1,q_2) - T(q_1,q_2)\right) dt$$

$$(2) \quad \text{s.t.} \quad \dot{R} = -q_1 - q_2$$

$$(3) \quad \dot{q}_1 = f(A,K)$$

$$(4) \quad \dot{P} = rP$$

with $C_R<0$, $C_{q1}=C_{q2}>0$, $C_{Rq1}=C_{Rq2}<0$, $C_{q1q1}=C_{q1q2}=C_{q2q2}>0$

$T_{q1}>0$, $T_{q2}>0$, $T_{q1q2}=0$, $T_{q2q2}>0$

where $q_1(t)$ is quantity of offshore oil sent to the low-cost refinery (California),

$q_2(t)$ is the quantity of offshore oil sent to the more distant refinery (Texas),

$P(t)$ is the price of low-quality offshore oil at both refineries,

$R(t)$ are proven reserves of offshore oil at the beginning of the period,

r is the expected growth rate of prices,

$A(t)$ is the quantity of Alaskan imports of higher quality crude to California, assumed to be exogenously determined,

$K(t)$ is the capital stock upgraded to process offshore oil,

δ is the producer's discount rate,

$C(\cdot)$ is the production cost function, and

T(•) is the transportation cost function.

The optimization problem, therefore, requires the producer to allocate production over time to refineries in the two locations (q_1+q_2) so as to maximize the present value of proven reserves, where reserves are assumed known.[2/] Marginal extraction costs (which are independent of the destination of the crude) are assumed to rise as the reserve is depleted -- implying that the least costly portions of the reserve are depleted first -- and increase with the total volume of production at any point in time (indicating perhaps a need for additional drilling activity to expand production).

Allocation of production between the two refining destinations is determined by a combination of transportation cost differentials and a binding capacity restriction for q_1. Regardless of mode, transportation costs are assumed to rise at an increasing rate with production to either destination (although they rise independently of the quantity sent to the other destination), but the minimum transportation cost for q_2 is assumed to be greater than the maximum cost of transportation for q_1. Capacity restrictions limiting q_1 can be eased by a decrease in imports of higher quality oil and/or through capital investment in upgrading facilities. Given the cost structure, therefore, q_1 is determined before any oil is targeted to q_2.

The assumption of rising marginal costs in transportation, of course, would seem at first to be inappropriate for the case of pipelines. Pipelines are usually assumed to have decreasing marginal costs. This latter assumption, however, is based on a comparison of two pipelines that process different quantities of crude oil. If a large and small pipeline are both run at capacity for the same length of time it is likely that the larger pipeline will have lower unit costs of transportation. On the other hand, if the two pipelines handle the same aggregate quantity over time, the higher volume transported in the larger pipeline results in the depletion of the reserve more rapidly, and hence has a shorter lifetime. The capital costs of construction, therefore, must be levied over a shorter period of time. As a result, assuming that the pipeline would be filled to capacity in each period, it is quite possible that the marginal cost (which is now equal to average cost) is positively related to the pipeline size beyond a certain range.[3/]

The Hamiltonian for (1)-(4) can be written:

(5) $H = e^{-\delta t}(P\bullet(q_1+q_2) - C(R,q_1,q_2) - T(q_1,q_2)) + \lambda(-q_1 - q_2)$

First order conditions for a maximum require that:

(6) $\partial H/\partial q_2 : \lambda = e^{-\delta t}(P - C_{q2} - T_{q2})$

(7) $\partial H/\partial R = -e^{-\delta t} C_R = -\dot{\lambda}$

Differentiating (6) with respect to time, equating the resulting derivative with the expression in (7), and replacing $\dot{P}$ with (4) yields the Euler equation for the flow of the resource sent to the more distant refinery:

$$(8) \quad \dot{q}_2 = \frac{(r - \delta)P + \delta(C_{q2} + T_{q2}) - C_{q2R}\dot{R} - \dot{q}_1 C_{q2q1} - C_R}{C_{q2q2} + T_{q2q2}}$$

As shown in (8), the rate of change in production dedicated to Texas refineries ($\dot{q}_2$) is determined by the growth rate of prices, the rate of change in production dedicated to California refineries ($\dot{q}_1$), and the shape of the cost functions. If California refineries increase their capacity to process offshore crude over time, $\dot{q}_1$ is positive, leading to a faster decrease in the quantity of Texas-bound oil over time. Given the assumption that it is always cheaper to send oil to California than to Texas, this result merely indicates that the advantages of spreading out shipments of oil to Texas over longer periods of time are diminished when the percentage of crude that can be handled at California facilities increases.

The price term in (8) also affects the rate of depletion. When the price grows at less than the firm's discount rate, the discounted present value of a barrel of oil falls to the firm in each period. Producers in that case have the incentive to produce as rapidly as possible, incurring higher costs of production and transportation to avoid the loss in the discounted real value of oil.

The advantages and disadvantages of using pipelines versus tankers can be seen in the context of equation 8. Tankers in this exercise are assumed to be capable of transporting any quantity of oil to refineries, with a relatively small increase in the marginal cost of transportation. Pipelines, on the other hand, are assumed to have decreasing marginal costs for any given pipeline size until the capacity of the pipeline is reached. Beyond that level, the marginal cost is assumed to be prohibitively large. In order to minimize transportation costs in the pipeline case, there is pressure to set $\dot{q}_2$ equal to zero and choose the level of q_2 that maximizes constrained profits. This is done so as to avoid higher unit transportation costs caused by the pipeline increasing its charges to recover its costs.[4/] In order for a pipeline transportation technology to be optimal (in comparison to a perfectly flexible system with similar overall costs), it is necessary to have a fairly constant desired flow of oil to the more distant refinery for a long period of time. If, on the other hand, the optimal flow drops off rapidly, then a pipeline solution imposes considerable constraints on the production flow relative to a flexible delivery system.

For $\dot{q}_2$ to equal zero, several parameters are important. The denominator in equation 8 is positive, so the sign of $\dot{q}_2$ depends on the numerator. As shown in equation 8, the sign of $\dot{q}_1$, the magnitudes of the derivatives, and increases in the growth rate of prices relative to the firm's discount rate are critical in determining the sign and magnitude of $\dot{q}_2$. Assuming that the derivatives are relatively small, the constraint imposed by a fixed versus flexible delivery system depends critically on the first two factors: the difference between the growth rate of oil prices and the firm's discount rate, and the pattern of sales to the low-cost destination. As shown in Section IV, the optimal depletion paths are especially sensitive to the price effect, although changes in other parameters affect the optimal size of the pipeline and the period over which it operates.

III. An Optimal Depletion Simulation Model

The simulation model for the offshore California relies on a highly simplified description of the situation. In spite of the simplifying assumptions, however, the model can be applied quite easily to a wide range of possible scenarios.

Production of oil from offshore reserves is assumed to be targeted to California and Texas refineries. Sales of offshore oil to California (CAL) are determined by the expression:

(9) $CAL(t) = CAL(t-1) + a_1[AL(t)-AL(t-1)]$,

where AL represents imports of high-quality oil from Alaska (or possibly other sources) to California refineries and are determined by the expression:

(10) $AL(t) = AL(t-1)^{a2}$.

The growth rate of offshore production dedicated to California, therefore, can be positive or negative depending on the change in Alaskan production refined in California (a_2), and the degree of substitutability of capacity between heavy and light crude (a_1).

Reserves are assumed to decline over time with production (there is assumed to be no change in the original reserve stock over time) using the equation:

(11) $RES(t) = RES(t-1) - CAL(t-1) - TEX(t-1)$

where TEX is offshore production sent to Texas. The real price of oil is also determined recursively using a constant real growth rate:

(12) $P(t) = (1+r) \cdot P(t-1)$

where r is the growth rate.

Production dedicated to Texas refineries is determined using a discrete time approximation to equation 8 above:

$$(13)\quad TEX(t) = TEX(t-1) + [(r-\delta)P + \delta(C_{TEX}+T_{TEX})\ C_{TEX,RES}(RES(t)-RES(t-1)) - (CAL(t)-CAL(t-1)C_{TEX,CAL} - C_{RES}] / [(C_{TEX,TEX}+T_{TEX,TEX})]$$

where the subscripts refer to derivatives of the production and transportation cost functions. The production and transportation cost functions are defined by:

$$(14)\quad C(t) = b_0 RES(t)^{b1}[CAL(t)+TEX(t)]^{b2}, \text{ and}$$

$$(15)\quad T(t) = c_0 TEX(t)^{c2} + d_0 CAL(t).$$ [5/]

where all costs are in constant dollars.

The solution of equation 13, of course, requires a value for TEX(t-1). To obtain an optimal solution, it is necessary to search over all possible values of TEX(t-1) to find the optimal initial value. The equation system in (9)-(15) is repeatedly simulated for possible starting values of TEX(t-1), running forward the production plans until reserves are exhausted or unprofitable to produce, and selecting the initial value that maximizes the real discounted present value:

$$(16)\quad PV = \sum_t [[CAL(t)+TEX(t)]P(t)-C(t)-T(t)]/(1+\delta)^t.$$

The resulting "optimal" paths can then be compared across scenarios.

IV. Simulation Results

The model described above was used to examine the conditions under which offshore producers would produce a pattern of production compatible with a pipeline technology (i.e., a constant level of production over time) without imposing any constraints on production. The resulting "base case," it should be noted, results in a relatively constant transportation cost over time, which is consistent the assumptions underlying a pipeline system. Three cases are then compared to this "base case" to evaluate the sensitivity of the base case assumptions to changes in the growth rate of oil prices, the growth rate of production dedicated to California refineries, and a narrowing of the relative cost of transportation between the two regions.

The "Base Case"

Values of the parameters for the base case are shown in Table 1. Real oil prices are assumed to grow 4.75 percent each year, while the firm's discount rate is assumed to be 6 percent. Discounted prices, therefore, are assumed to fall for producers over time. Alaskan oil is assumed to decay at the rate of .5 percent per year, with California production replacing only a very small portion of the Alaskan decline. This latter assumption is consistent with the wide difference in quality between the two oils.

Any choice of cost parameters for this case is necessarily arbitrary. There is very little experience with extended production from the chief producing zone, the Monterey formation, in these newly discovered offshore fields. How production will decrease over time and what additional costs

TABLE 1
BASE CASE VALUES FOR PARAMETERS AND MODEL VARIABLES

Parameters:

Substitutability of offshore and Alaskan oil	a_1 =	-.050
Elasticity of oil supply from Alaska	a_2 =	.995
Rate of price increase in offshore oil	a_3 =	.0475
Discount rate for firm	a_4 =	.060
Elasticity of production costs to change in reserves	b_1 =	-1.200
Elasticity of production costs to change in level of production	b_2 =	1.600
Elasticity of transportation costs to change in quantity transported to Texas	c_2 =	1.300
Unit cost of transporting oil to California	d_0 =	.500

Initial Values of Variables:

Alaskan oil refined in California (AL) = 602 MBD
Offshore California oil refined (CAL) = 74.6 MBD
Wellhead price of offshore oil (P) = 22.3 dollars per barrel.
Reserves of offshore oil (RES) = 2.5 billion barrels.

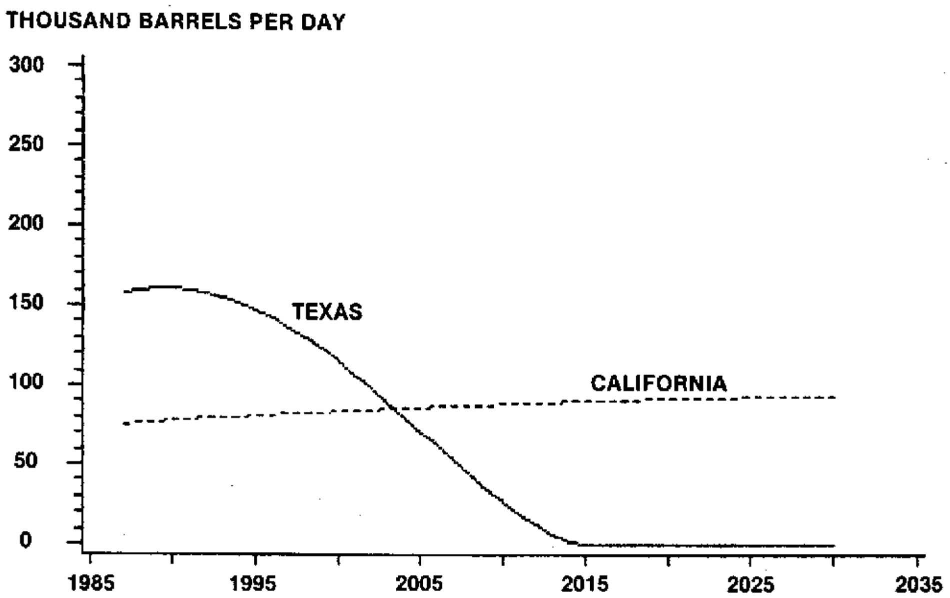
will be required to maintain production levels is subject to conjecture. To guide the selection of the parameters, theoretical properties and published estimates of resource depletion were used. The parameters are consistent with the theoretical properties of the cost function: an increase in costs with decreases in reserves over time and from higher production within a given time period. Costs increase as the constraints of geology and capital stock limit the producers ability to change radically the production level within a single time period. Transportation costs rise per unit because of the increasing average costs when the cost of construction or adjustment to capital stock are included.

Although properties of the parameters are consistent with economic theory and intuition, a more difficult question to address is whether the actual numerical values of the parameters in Table 1 are reasonable. The lack of available information makes it difficult to have confidence in the value of a particular parameter. Fortunately for this analysis, the model is relatively insensitive to changes in the cost function parameters. Changes of 50 percent in the values of the parameters do not produce significant alteration in the qualitative nature of the results. This is not surprising given the small component costs form relative to the overall rent the producer is earning.

Initial values of the variables other than TEX are also shown in Table 1. Alaskan production, the initial price for offshore oil, the quantity of offshore oil refined in California refineries, and proven reserves are based on estimated values for 1987.[6/]

CHART 1.

BASE CASE TRAJECTORY OF OFFSHORE OIL SENT TO CALIFORNIA AND TEXAS REFINERIES.



The optimal depletion paths for offshore oil sent to California and Texas in the base case are shown in Chart 1. Given the set of base case parameters, production shipped to Texas is relatively flat between 1987 and the year 2000, averaging 155 thousand barrels/day (MBD) with a peak of 170 MBD, after which the decrease accelerates. Until the year 2000, production is fairly constant with less than 20-percent deviation of the optimal path from the mean of the first fourteen years, and less than 10 percent deviation in any of the first 10 years from the mean level for that period.

Although the results support a pipeline scenario in that they require relatively small restrictions on the production path for the first 10 years, the estimated flows are lower than the capacity of currently planned pipelines. The smallest pipeline being considered, the All-American proposal, has a capacity of 300 MBD.[7/] Much of this difference can be explained by the proponent's plan to transport Alaskan oil and other crudes produced in California to the Gulf Coast and other eastern U.S. destinations.[8/]

Offshore sales to California refineries, also shown in Chart 1, increase slowly during the period prior to 2033, at which time production ceases. The model, it should be noted, does not deplete all of the reserves because the cost of production becomes prohibitive as reserves are driven to zero (equation 14).

The argument for pipelines in this case would be fairly strong. Because the production level remains fairly steady, imposing a pipeline -- perhaps a smaller line than currently envisioned -- would not significantly alter the nature of the depletion path.

The Effect of Prices

With a single exception, parameters used in the base case were selected because they represent a reasonably realistic approximation of what might be expected. The one exception is the growth rate used for oil prices. The base case assumed a real growth rate of 4.75 percent for oil prices throughout the period. Such an increase would be considered high given recent price movements. To observe the sensitivity of the base case result to changes in the price growth rate, the 4.75 percent base case rate is replaced by a lower rate of 3.5 percent. Although this may be considered on the high side as well, it is illustrative of the importance of the effect of price expectations on the outcome.

As shown in Chart 2A, changing the growth rate in prices has a major effect on the nature of the depletion paths. Turning first to the path for Texas, the initial level of production is considerably higher in the case with the slower growth rate, and the level of production declines rapidly. The volume in the initial period is 360 MBD which is far in excess of the offshore production that the planned pipelines are capable of transporting. As Chart 2B illustrates, the change for California is limited: the only difference from the base case is the earlier exhaustion of the reserves as depletion of the resource occurs more rapidly. This result reflects the capital constraint on refining in California which causes more of the production to be shipped to Texas. In the base case, it should be noted, 43 percent of total reserves are processed by Texas refineries, compared with 55 percent in the case with a slower growth rate in prices.

CHART 2A.

THE EFFECT OF A SLOWER GROWTH IN PRICES
ON SHIPMENTS OF OFFSHORE OIL TO TEXAS REFINERIES.

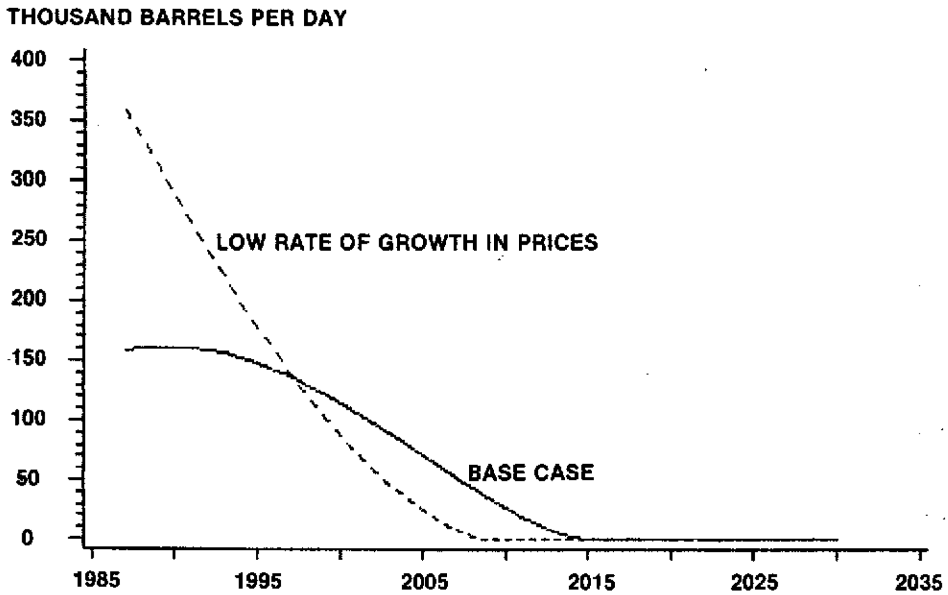
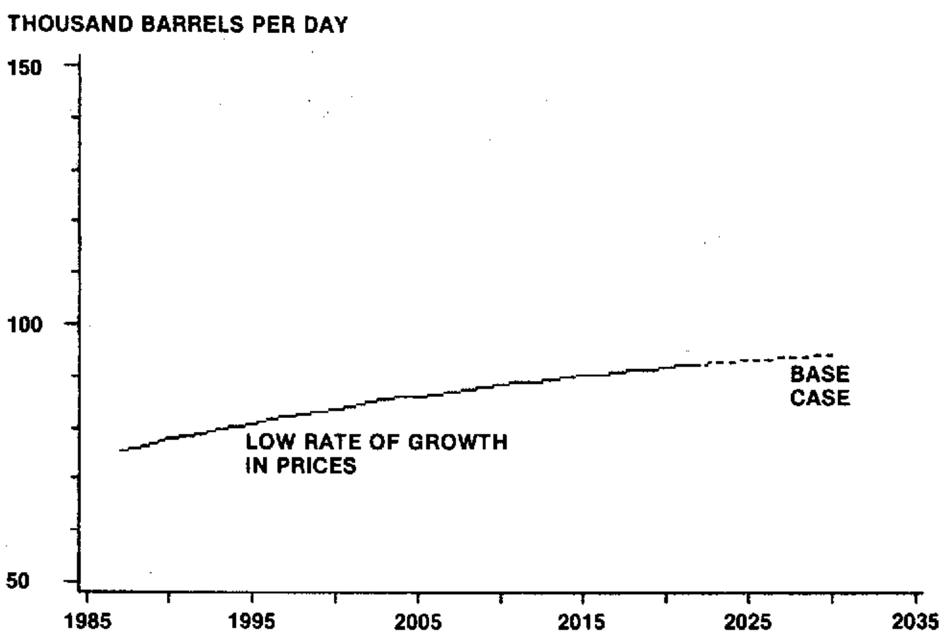


CHART 2B.

THE EFFECT OF A SLOWER GROWTH RATE IN PRICES
ON SHIPMENTS OF OFFSHORE OIL TO CALIFORNIA REFINERIES.



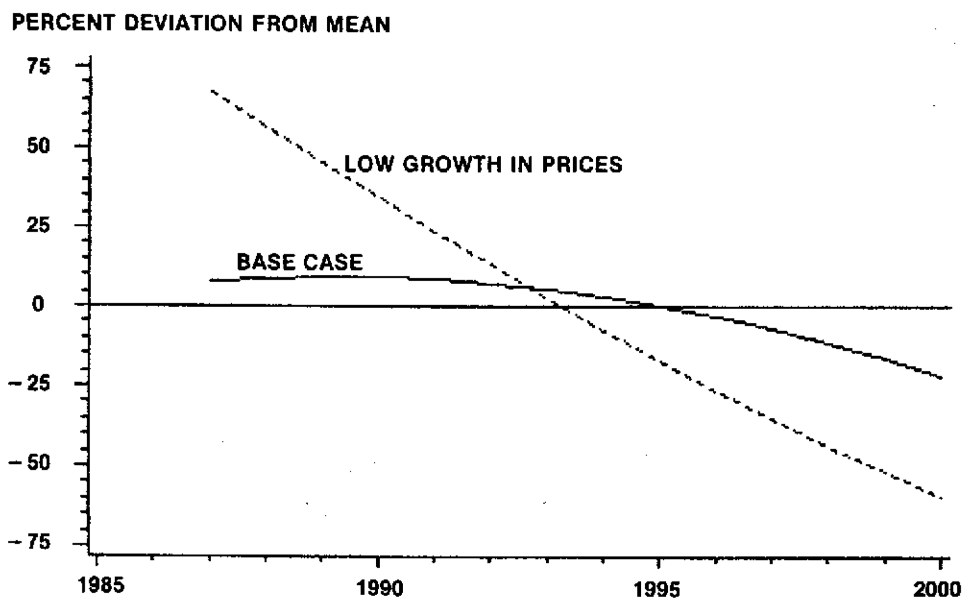
This result is consistent with theoretical findings that decreasing the growth rate of prices relative to the discount rate shortens the depletion period. With less rapid increases in the price, the discounted present value of _in situ_ rents declines more rapidly, making it advantageous to incur higher costs of production and transportation -- both of which are assumed to rise at increasing rates with additional output -- and not delay extraction.

Changes in the relative shares shipped to CAL and TEX are consistent with the reduction in present value associated with the lower growth in prices. Because the value of the oil in the ground declines at a faster rate than in the base case, there is more incentive to get the oil out quickly. As a result, there is a larger penalty associated with waiting for the less-costly California facilities to process the offshore oil.

The implications of the low-priced scenario for the pipeline case are quite significant. The imposition of a pipeline technology would require major departures from the depletion path shown in Chart 1. Chart 3 compares the deviation of the optimal production path from each case's average production level for the first 14 years. As shown in the Chart, a fixed production path required for a pipeline would place a much greater restriction on the production path in the case of a lower growth rate in prices: deviations from the average exceed 70-percent at the beginning and end of the 14-year period. By contrast, the restriction does not exceed 20-percent for the base case scenario.

Because of the greater variation in production in this case, requiring a pipeline technology would most likely force producers to extract the

CHART 3.
DEVIATIONS OF THE OPTIMAL PRODUCTION PATH
FROM THE MEAN PRODUCTION LEVEL DURING THE PERIOD 1987-2000.
COMPARISON OF THE BASE CASE WITH THE LOW-PRICE GROWTH RATE CASE.



resource at a slower rate than they would prefer, and for a longer period of time. The estimated loss of present value is about 20 percent. As a result, the argument favoring a pipeline on economic grounds must be based on the assumption that the unit transportation costs of pipelines are sufficiently lower than a more flexible system such that producers can obtain even higher discounted profits under a fixed path than they could get under that shown in the low-price case in Chart 2A.

The Effect of Substitutes

The depletion path is also affected by the availability of refining capacity in California. Under the base case scenario, California refineries are assumed to increase their processing of offshore oil at a very slow rate. Should the supply of Alaskan oil be reduced (or increased) at a more rapid rate than indicated in the base case, and/or should California refiners add capital to upgrade their capability to process heavy crude, the depletion paths are likely to be altered.[9] Charts 4A and 4B show the expected production being shipped to Texas and California, respectively.

A faster growth in heavy oil refinery capacity in California is proxied here by a faster decay rate in Alaskan production relative to the base case. Using a decay rate of 10 percent, instead of the base case rate of .5 percent, offshore sales to California refineries are found to increase to 67 percent of produced reserves, up from 57 percent in the base case. The amount refined in Texas during the initial period is 140 MBD. Compared to the base case, the production sent to Texas refineries during the period 1987-2000 averages 125 MBD compared to 155 MBD in the base case.

CHART 4A.

THE EFFECT ON SHIPMENTS TO TEXAS OF AN INCREASED CAPABILITY
TO PROCESS OFFSHORE OIL AT CALIFORNIA REFINERIES.

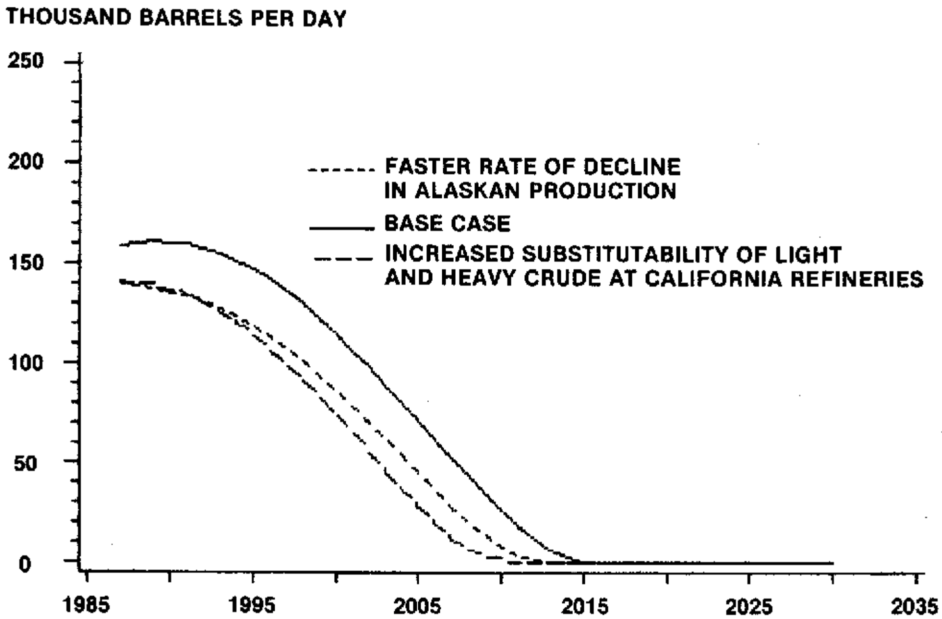
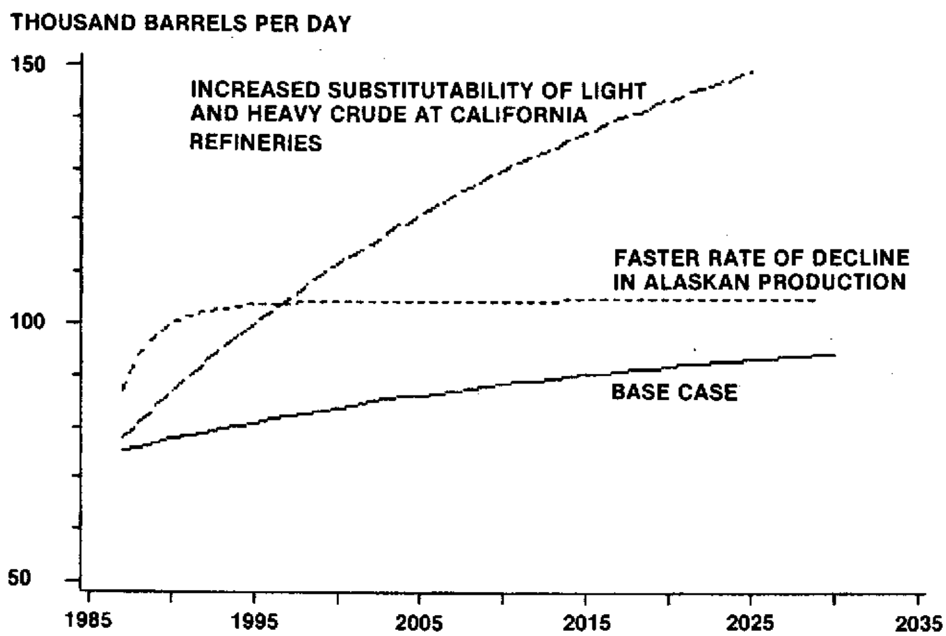


CHART 4B.

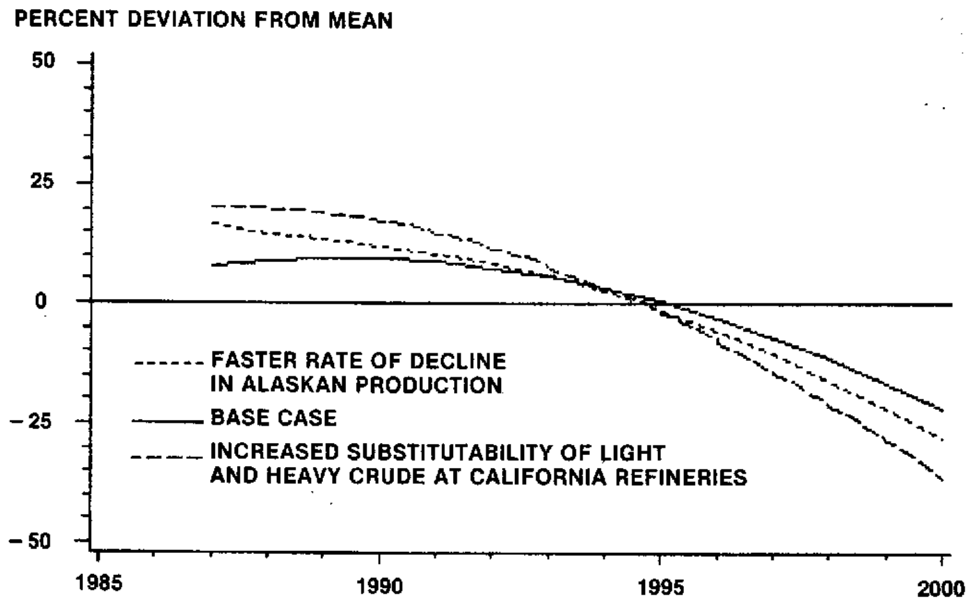
THE EFFECT ON SHIPMENTS TO CALIFORNIA OF AN INCREASED CAPABILITY
TO PROCESS OFFSHORE OIL AT CALIFORNIA REFINERIES.



As Charts 4A and 5 demonstrate, the case for a pipeline is not harmed much by this change, although the size of the "optimal" pipeline is reduced. The change in California capability leads to a faster depletion of the offshore reserves, but the pattern of sales to Texas refineries remains fairly flat for the period 1987-2000. Because the cost of constructing a pipeline does not vary much with size, the pipeline corresponding to the faster growth rate in sales to California would require higher tariffs to cover the slightly higher average fixed costs.

A larger effect on the depletion paths occurs with changes in the substitution parameter at California refineries. Maintaining the decay rate of Alaskan crude at the base case value of .5 percent, but increasing the elasticity of substitution between the two crudes from .05 to .2 leads to more drastic changes in the amount of offshore crude refined in California. This experiment proxies for more rapid improvements to the capital stock at California refineries or for an unforeseen increase in higher quality offshore crudes. The change in shares to each destination, also shown in Charts 4A and 4B, is quite significant. The percentage of produced reserves refined in California increases from 57 percent in the base case to 83 percent, with 193 MBD being refined in 1995. The profile of production transported to Texas is unfavorable in both volume and duration for a pipeline. Chart 5 illustrates the large increase in percent variation in this latter case relative to the base case. For nearly all years prior to the year 2000, the percent deviation of the optimal path from the 14-year average is double that found in the base case.

CHART 5.
DEVIATIONS OF THE OPTIMAL PRODUCTION PATH FROM THE MEAN PRODUCTION LEVEL DURING THE PERIOD 1987-2000. COMPARISON OF THE BASE CASE WITH THE HIGHER SUBSTITUTABILITY CASES.



Changes in the capability of California refineries to handle heavy crude, therefore, have two implications for the pipeline option. First, the reduction in the share of oil shipped to Texas may decrease the optimal size of the pipeline (raising average unit costs). Second, the more rapid depletion of the offshore reserves would force the pipeline company to raise its charges so as to recapture its capital expense in a shorter period of time. If the ability of California refineries to handle offshore crudes increases significantly, these factors could make pipeline tariffs prohibitively expensive.

The Effect of Relative Transportation Costs

As mentioned in the previous subsection, the pipeline case is affected by changes in the intertemporal distribution of offshore oil between California and Texas refineries. In addition to being a function of the upgrading capability of California refineries, the decision to put off current shipments to Texas refineries in favor of future sales to California refineries depends on the savings in relative transportation costs that such a decision would generate.

To observe this effect, the average unit cost of transportation to California refineries is increased from $0.50/barrel in the base case to $1.50/barrel. The results of this experiment on production sent to Texas relative to the base case are shown in Charts 6 and 7.

The increased cost of transporting oil to California decreases the value of delaying depletion for processing at California refineries. With higher average unit costs of transportation to California, the cost of

CHART 6.
THE EFFECT ON SHIPMENTS OF OFFSHORE OIL
TO TEXAS REFINERIES OF TRANSPORTATION COST DIFFERENTIALS.
COMPARISON OF THE BASE CASE TO THE CASE WITH HIGHER COSTS
OF SHIPPING TO CALIFORNIA.

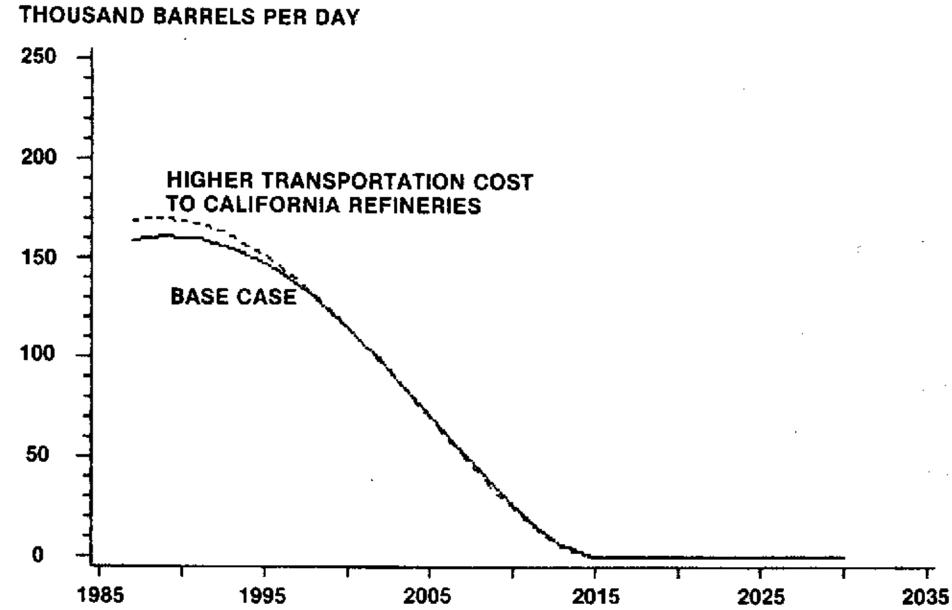
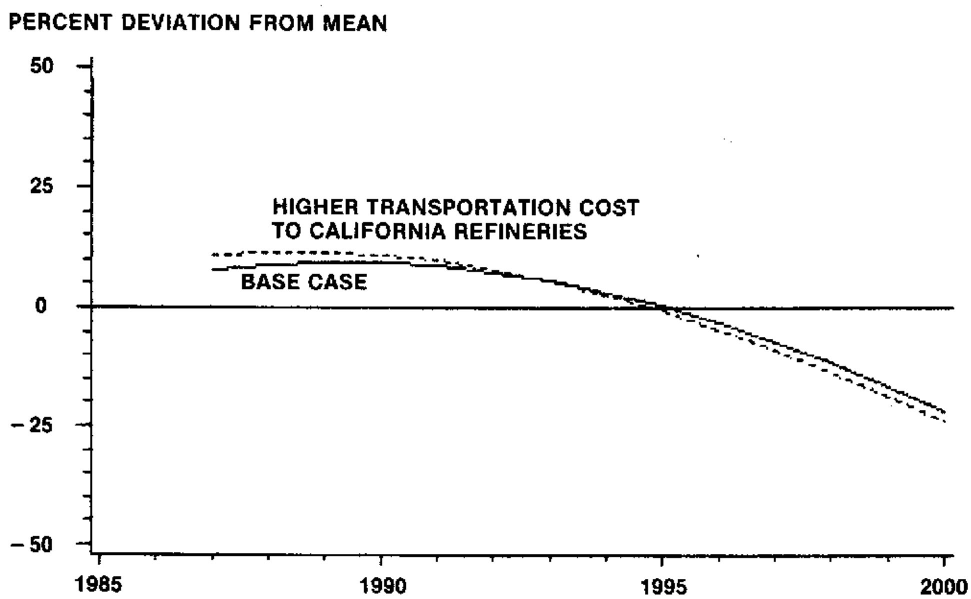


CHART 7.
DEVIATIONS OF THE OPTIMAL PATH
FROM THE MEAN PRODUCTION LEVEL DURING THE PERIOD 1987-2000.
COMPARISON OF THE BASE CASE TO THE CASE WITH HIGHER COSTS
OF SHIPPING TO CALIFORNIA.



transporting oil to Texas becomes less of a disincentive, resulting in slightly higher sales to Texas over a longer period of time. Because the unit cost of transportation is still lower for California refineries, however, there is no significant change in the pattern of sales to California, with the exception of the shorter time to depletion. Overall, the effects are rather small.

Changes in the relative transportation costs between shipping to Texas and shipping to California, therefore, have minor effects on the case for a pipeline. Because the "optimal" path is steeper, imposing a pipeline would be a more binding constraint with a narrower gap between relative transportation costs than with a wider gap. Chart 7 illustrates the slightly greater deviations from the mean in this case as opposed to the base case.

V. Conclusions

Results from the theoretical and simulation models indicate that the optimal depletion path of an exhaustible resource is likely to exhibit a pattern that would be inconsistent with the fixed quantity requirements of a pipeline transportation network. Although it is possible that the situation may be such that a fixed production schedule could result, the sensitivity of such a schedule to minor fluctuations in the model's parameters could be quite large, suggesting that the chances of a production profile meeting the optimum requirements for a pipeline are far from likely.

Price expectations, in particular, were shown to be important in forming the desired depletion path for an offshore producer. As the gap between the growth in prices and the firm's discount rate widens, the producer's desire to produce as rapidly as possible (resulting in a rapidly falling depletion schedule) is enhanced. Changes of one to two percentage points in price expectations were shown to be sufficiently large to change a flat production plan into a sharply falling schedule.

Even if the optimal schedule does happen to be flat, several additional variables need to be taken into account in determining the size and profitability of the pipeline. If California refineries are able to increase their capacity to handle the heavier crude, there will be a reduction in production sent through the pipeline. Furthermore, the spread between transportation cost charges to reach California and Texas refineries could have an effect on the quantity shipped through the pipeline.

Pipelines, therefore, are likely to alter the production plan for offshore producers relative to that which would result with tankers. Two caveats, however, are important. First, this is not a general indictment of pipelines, but a suggestion that, in certain instances, they may dissipate some of the producer's rent. The producer loses rent if forced to alter production from the present value maximizing path. Any deviation requires incurring higher transportation or production costs or foregoing income. In such a case the cost of a pipeline is greater than the tariff suggests. Second, capital constraints can exist with shipping. This is especially true in the United States where there are significant barriers to entry,[10/] although it does not appear to be a significant problem with the volumes we are discussing.

Furthermore, the results of this study could argue for a combination of a pipeline and tankers. Cost advantages attributed to pipelines could be exploited for a base level of production (set well below the desired initial level of production), with tankers used to carry any additional quantities. Over time, the quantity shipped in tankers would presumably decline until only the pipeline was used.

To summarize, not only differences in unit costs of transportation between different technologies, but the effect that the imposition of the technology may have on the intertemporal allocation of production between the two locations should be considered when deciding about the appropriate technology to use.

Footnotes

1. This assumes that most California onshore production will continue to be refined in the state.

2. Although offshore development is being undertaken by a large number of producers, it is assumed that the depletion of the offshore reserves can be modeled as if a single producer were involved. This assumption eliminates any inefficiencies that may result from an individual producer attempting to maximize profits through production rates designed to capture oil from neighboring fields, resulting in higher pumping costs for all producers.

3. For the purposes of the theoretical model (which allows for a perfectly flexible transportation technology), it is also assumed that marginal costs increase with quantity within each period. Clearly in the case of a pipeline, once constructed the minimum cost solution would be to run the pipeline at or near capacity. Such a solution can be modeled in this framework as a special case, where the problem is to choose a quantity q_2 that is constant over time.

4. This assumption implies that pipelines will attempt to evenly amortize the capital cost of construction over time. If they attempt to recapture the costs as a function of expected declining production patterns -- and charge a higher rate for higher volume, the problem becomes similar to that in the more flexible case. Should FERC allow a flexible tariff schedule for a pipeline to be developed, in fact, the transportation costs of using a pipeline could be structured so as to not affect the depletion path of the producer.

5. For each experiment the cost function was calibrated using actual costs as a reference point. Given the set of cost parameters, the intercept was determined such that the cost function passed through that reference point.

6. A variety of different sources were analyzed for model inputs. These include the Annual Petroleum Review, California Energy Commission, 1983 and 1984; Oil Transportation Plan, Santa Barbara County, 1984; Exxon Pipeline Feasibility Study, Santa Barbara County, 1983; PADD V Petroleum Supply/Demand Forecast, Dames and Moore; and various articles in Oil and Gas Journal and Petroleum Intelligence Weekly.

7. A description of the All America pipeline proposal can be found in the application materials submitted to the California State Lands Commission.

8. Small amounts of Alaskan and other crudes produced in California will probably be transported in these pipelines. When these quantities are excluded, the amount of OCS crudes being shipped total approximately 225 MBD.

9. One possible policy change that could lead to a reduction in oil shipped from Alaska, of course, would be legislation removing the restriction against exporting domestic crude similar to that contemplated in a recent proposed amendment to the Export Administration Act.

10. Section 27 of the Merchant Marine Act of 1920, also known as the Jones Act, requires the use of U.S. flag vessels for trade between U.S. ports.

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