

Siebert, Horst

**Working Paper**

## The intertemporal supply of natural resources and the recycling of Hotelling rents: The case of the Saudis

Beiträge zur angewandten Wirtschaftsforschung, No. 189/81

**Provided in Cooperation with:**

Kiel Institute for the World Economy – Leibniz Center for Research on Global Economic Challenges

*Suggested Citation:* Siebert, Horst (1981) : The intertemporal supply of natural resources and the recycling of Hotelling rents: The case of the Saudis, Beiträge zur angewandten Wirtschaftsforschung, No. 189/81, Universität Mannheim, Institut für Volkswirtschaftslehre und Statistik, Sonderforschungsbereich 5: Staatliche Allokationspolitik im marktwirtschaftlichen System, Mannheim

This Version is available at:

<https://hdl.handle.net/10419/4057>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*

51 2487 A 18

75

Institut für Volkswirtschaftslehre und Statistik der  
Universität Mannheim

Sonderforschungsbereich 5

Staatliche Allokationspolitik im marktwirtschaftlichen System

The Intertemporal Supply of Natural Resources  
and the Recycling of Hotelling Rents. The Case  
of the Saudis

Horst Siebert\*

Discussion Paper No. 189/81



BEITRÄGE  
ZUR  
ANGEWANDTEN WIRTSCHAFTSFORSCHUNG

1981

K

1593

The Intertemporal Supply of Natural Resources  
and the Recycling of Hotelling Rents. The Case  
of the Saudis

Horst Siebert\*

Discussion Paper No. 189/81

I am grateful to Robert S. Pindyck for useful comments. Research leading to this paper was made possible by financial support and a scholarship from the "Stiftung Volkswagenwerk" and the hospitality and support of the Center for Energy Policy Research, MIT Energy Laboratory.

This paper has also been published as MIT Energy Laboratory Working Paper No. MIT EL 81-050WP.

### ABSTRACT

In this paper, we consider the case of a resource-exporting country that invests part of its resource earnings in the international capital market. We can show that the recycling of Hotelling rents introduces an incentive to supply more resources today and thus alleviates the resource shortage for the present generation. But the other side of the coin is that scarcities in the future will be more severe, that quantities extracted will decline more rapidly, that exhaustion will occur at an earlier date and that the price of the natural resource will rise faster. The paper also shows that the introduction of a capital market with a given interest rate separates the problem of optimal consumption and the optimal intertemporal supply of natural resources.

The Intertemporal Supply of Natural Resources and the Recycling  
of Hotelling Rents. The Case of the Saudis

Horst Siebert

The Hotelling rule (1931) of intertemporal supply behavior is derived for a competitive supplier of natural resources in a partial equilibrium framework where the recycling of the Hotelling rents is not further considered. This model of a profit maximizing firm cannot be used for the explanation of the intertemporal supply behavior of a resource exporting country if that country uses part of its resource earnings for portfolio or real investment in the international capital market. In this paper, we analyze the intertemporal supply behavior of a resource exporter when the recycling of resource earnings is explicitly taken into consideration. We will compare a situation in which the Hotelling rents are not recycled with the case where resource earnings are reinvested.

The basic proposition is: A resource-exporting country that uses part of its earnings from natural resources to build up financial capital will have an incentive to supply more resources today and thus alleviate the resource shortage for the present generation. But the other side of the coin logically is that the country becomes less dependent on resource earnings in the future and will have a smaller incentive to extract resources in future periods. Although the price of the resource will be lower initially, the price will rise faster and exhaustion occurs at an earlier date.

The price setting and the supply behavior of the OPEC countries has been analyzed in a number of models, for instance by Cremer and Weitzman (1976), Hnyilicza and Pindyck (1976), and Pindyck (1978; 1981). The

recycling of petro-dollars is partly addressed by Schmalensee (1976) and explicitly analyzed by Calvo and Findlay (1978). They, however, neglect the "exhaustibility of oil" (p. 524). In a more recent paper, Hoel (1981) has introduced the accumulation of financial wealth by a resource extracting monopolist and applied his results to the OPEC case. In contrast to Hoel, this paper is more specifically tailored to analyzing the incidence of recycling, i.e. to the comparison of the recycling with the non-recycling scenario. We explicitly introduce demand behavior, market equilibrium in the resource market and balance of payment considerations.

The assumptions of the model are presented in Section 1. The necessary conditions for a welfare maximum of the resource exporting country without recycling are discussed in Section 2. In Section 3, recycling is explicitly introduced. The two cases are compared in Section 4. Finally, some potential extensions are indicated.

### 1. Assumptions

A country owns a stock of natural resources  $R_0$ . It sells  $q_t$  units of resources in the world market at price  $p_t$ . The change in the stock of the nonrenewable resources is given by

$$\dot{R}_t = -q_t \quad (1)$$

In each period, the country imports a consumption good  $D$  at the price  $\pi$ . Let the prices  $p$  and  $\pi$  be denoted in foreign currency. If no capital exports or imports take place, the balance of payment restraint in foreign currency is defined as

$$pq - \pi D \geq 0 \quad (2)$$

This restraint can also be interpreted as the budget restraint for the resource-exporting country.

Alternatively, we will assume that the country can buy financial assets in the world capital market; initially, its financial assets are zero. The assets  $V_t$  yield an interest rate  $r$ . Let the assets be expressed in terms of foreign currency. Resources can be extracted without costs. Then the country's income  $Y_t$  in foreign currency is defined as

$$Y_t = p_t q_t + r V_t$$

where  $p_t q_t$  represent the Hotelling rents. The change in the stock of the financial assets is given by

$$\dot{V}_t = p_t q_t + r V_t - \pi D_t \quad (2a)$$

Equation 2a can also be interpreted as the balance of payments where the right side contains the net balance of the current account, i.e., trade plus services (interest payments), and the left side indicates capital movements.  $\dot{V} > 0$  indicates the accumulation of financial capital and capital exports;  $\dot{V} < 0$  denotes the reduction of financial capital or capital imports. The resource exporting country has a concave welfare function,

$$W = W(D) \quad \text{with } W_D > 0, W_{DD} < 0 \quad \text{and} \quad \eta(D) = - \frac{D W_{DD}}{W_D} > 0, \quad (3)$$

where  $\eta(D)$  defines the elasticity of the marginal utility function. The country maximizes its welfare from consumption over time  $(0, \infty)$  where future welfare is discounted with the country's given time preference rate  $\delta$ .

Demand behavior of the importing country with is given

$$q = f(p) \quad \text{with } f_p < 0 \quad \text{and} \quad \epsilon_{qp} = f_p \frac{p}{q} < 0. \quad (4)$$

Demand will become zero, when  $p = \bar{p}$ , i.e.,  $f(\bar{p}) = 0$ .

Markets or an auctioneer will set resource prices in such a way that quantities supplied are equal to quantities demanded in each period and over all periods (stock equilibrium). Specifically, the initial price  $p_0$  of the resource has to be set in such a way that supply equals demand over all periods. Whereas the auctioneer or the markets, including a set of perfect future markets, set the equilibrium prices, the resource exporting country takes the resource price as given and does not anticipate demand. Thus, the resource exporting country determines its supply for a given set of prices. If at a given set of prices markets do not clear, the auctioneer will call out a new set of prices until equilibrium prices are found.

Finally, we assume that the initial price  $\pi_0$  of commodity D and its change over time,  $\pi_t$ , are exogenously given.

## 2. Extraction without Recycling

As a frame of reference we first analyze the case in which no recycling occurs. The optimization problem is

$$\text{Max} = \int_0^{\infty} e^{-\delta t} W(D) dt \quad (5)$$

s.t. (1) and (2).

The Hamiltonian H and the Lagrangian L are defined as

$$H = W(D) + \lambda(-q) \quad (5a)$$

$$L = H + \rho(pq - \pi D) \quad (5b)$$



We have the following necessary conditions for a welfare maximum

$$\frac{\partial L}{\partial D} = W_D - \rho \pi = 0 \quad \implies \quad W_D = \rho \pi \quad (5c)$$

$$\frac{\partial L}{\partial q} = -\lambda + \rho p = 0 \quad \implies \quad \lambda = \rho p \quad (5d)$$

$$\dot{\lambda} = \delta \lambda - \frac{\partial H}{\partial R} \quad \implies \quad \hat{\lambda} = \delta \quad (5e)$$

$$\frac{\partial L}{\partial \rho} = pq - \pi D \geq 0 \quad \rho \frac{\partial L}{\partial \rho} = 0 \quad (5f)$$

The Lagrangian multiplier  $\rho$  is the shadow price of one unit of foreign exchange earnings. We assume in this section that the balance of trade is in equilibrium so that  $\rho > 0$ . From equations 5d and 5e, the percentage change in  $\rho$  is given by

$$\hat{\rho} = \delta - \hat{p} \quad (6)$$

Consider the case  $\delta < \hat{p}$  in which the resource price rises faster than the time preference. In a closed economy this means that it is not worthwhile to extract the resource. For an open economy, equation 6 requires for  $\delta < \hat{p}$  that the shadow price of one unit of foreign currency earned, expressed in current value, falls over time. This case may arise if the price of the imported commodity falls heavily. In the following we rule out this case assuming  $\delta > \hat{p}$  which is the usual condition given for extraction to take place. This assumption implies that  $\rho$  increases over time.

Consider the case  $\delta < \hat{p}$  in which the marginal contribution of one unit of foreign currency earned to the objective function rises faster than the time preference. Then, with given prices, it would be optimal to hold foreign currency for the next period. We have, however, required that the trade balance be in equilibrium. Consequently,  $\delta < \hat{p}$  can only

occur if the price of the natural resource falls over time (compare equation 6). In order to exclude this possibility, we must assume that  $\delta > \hat{p}$ . For similar reasons, we assume that the price of the imported commodity does not surpass the time preference so that we have

$$\delta > \hat{p}, \hat{p}, \hat{\pi}. \quad (6a)$$

The assumption  $\delta > \hat{p}$  implies that  $\hat{p} > 0$ .

Differentiating equation 5c with respect to time and substituting equation 6 we have

$$\hat{D} = \frac{1}{-n(D)} (\delta - \hat{p} + \hat{\pi}) \quad (6b)$$

For consumption to decline it is sufficient that

$$\delta + \hat{\pi} > \hat{p} \implies \hat{D} < 0 \quad (6c)$$

For  $\hat{\pi} = 0$ , this is the usual condition for extracting resources. If  $\hat{\pi} > 0$ , the costs of waiting do not only include the time preference but also the price rise of the imported commodity.

Define  $t = p/\pi$  as the terms of trade of the resource exporting country. Then equation 6c may be rewritten as

$$\delta > \hat{p} - \hat{\pi} = \hat{t} \implies \hat{D} < 0. \quad (6d)$$

i.e., consumption will decline over time if the time preference is larger than the change (improvement) in the terms of trade. Given condition (6c), the decline of consumption will be more pronounced the larger the time preference rate  $\delta$ , i.e., the higher is the original consumption level, the smaller the price rise of the natural resource and the larger the price rise of the imported commodity.

Equation 6b may also be rewritten as

$$\hat{p} = \delta + n\hat{D} + \hat{\pi} \quad (6e)$$

which defines an optimality condition resembling the Ramsey rule in models of optimal economic growth (Dasgupta and Heal, 1979, p. 297). The left side of equation 6d denotes the benefit of letting one unit of a resource sit in the ground for one period. The right side indicates the costs of waiting.  $\delta + n\hat{D}$  is the consumption rate of discount (Dasgupta, 1978, p. 7). Adding price, the change of the imported commodity defines the consumption rate of discount for a resource exporting country.

Alternatively, equation 6e may be rewritten as

$$\hat{t} = \hat{p} - \hat{\pi} = \delta + n\hat{D} \quad (6f)$$

This equation requires that the consumption rate of discount, i.e., the costs of waiting, must be equal to the improvement in the terms of trade, i.e., the benefits of waiting.

For given  $\hat{\pi}$ , the optimality condition 6b is not sufficient to determine both  $\hat{D}$  and  $\hat{p}$ . To specify a solution we need additional equations. From the demand equation we have

$$\hat{q} = \epsilon_{qp}\hat{p}. \quad (7)$$

Differentiating equation 2 with respect to time yields

$$\hat{p} + \hat{q} = \hat{\pi} + \hat{D} \quad (8)$$

which requires equilibrium in the trade balance. The three equations 6b, 7 and 8 contain the variables  $\hat{q}$ ,  $\hat{D}$ , and  $\hat{p}$ . We have

$$\hat{p} = \frac{\delta + \hat{\pi}(1 - n)}{1 - n(1 + \epsilon_{qp})} \quad (9)$$

For an elastic demand of the resource importing country, the denominator of equation 9 is always positive. For prices to rise it is sufficient that  $1 > n$ . Then, the denominator will be positive even if demand of the resource importing country is inelastic. The elasticity of the marginal utility function  $n$  can be interpreted as the demand or

import elasticity of the resource exporting country. This follows from condition 5c which implicitly defines a demand function  $D = D(\pi, \rho)$ . Let  $\epsilon_{D\pi} = D \frac{\pi}{D}$ . Assuming  $\rho$  as constant we have  $\epsilon_{D\pi} = -\frac{1}{\eta} < 0$ . Consequently, a high elasticity of demand of the resource exporting country for commodity D is sufficient for prices of the natural resources to rise. This condition implies that the resource exporting country can easily reduce its demand for commodity D; consequently, it can also adjust the supply of natural resources since it does not need foreign exchange earnings very badly. We see that in this model the supply of natural resources thus is directly linked to the demand of the consumption good.

The price rise will be stronger, the higher the time preference, the less elastic is the demand of the resource importing country for natural resources and the more elastic is the demand of the resource exporting country for the consumption good D. From equation 7 q will fall over time, and from equation 6b D will fall. With quantities being reduced, the elasticities  $\epsilon_{qp}$  and  $\epsilon_{D\pi}$  will change. Assuming a linear demand function, demand of the resource importing country will become more elastic. This makes for a smaller price rise. At the same time,  $\eta$  may rise and the elasticity of the resource exporting country with respect to D will fall. This again reduces the price rise. The price will approach the value  $\bar{p}$  where demand becomes zero. From the transversality condition we have

$$e^{-\delta T} \lambda(T)q(T) = e^{-\delta T} W(D) \quad (10)$$

We can rule out the case that the present value of the shadow price  $\lambda(T) = 0$  because this would imply that  $\rho_0 p_0 = 0$  so that either the resource is not scarce or foreign earnings have no positive value in the

initial period. Also  $q(T) = f(\bar{p}) = 0$  since  $\bar{p}$  is reached. With the present value of the shadow price  $\lambda(T)$  being positive, and with  $q(T) = 0$ ,  $D$  must be zero in terminal time  $T$ . From equation 5c it follows that with rising  $\rho$  and  $\pi$ ,  $W_D$  will rise from period to period and thus terminal time will be infinite.

In Figure 1, the optimality conditions of each period are illustrated. Assume that  $\pi$  is constant. For given  $\rho$ , consumption is determined by equation 5c or by the marginal utility schedule in the upper quadrant of Figure 1. Once  $D$  is specified, with  $\rho$  given and the price  $p$  being set by the market, the supply of natural resources is also determined. In the lower quadrant of Figure 1, let  $\text{tg } \alpha = \pi/p$ . With  $D$  specified and  $\text{tg } \alpha$  given, the quantity supplied  $q = D\pi/p$  is also specified. The straight line  $OB$  denotes the budget restraint of the resource exporting country, i.e., its trade balance.

With rising  $\rho$ ,  $W_D$  increases and the quantity consumed declines, i.e., the country works its way up the marginal utility schedule. At the same time,  $\pi/p$  declines with rising  $p$ ,  $\text{tg } \alpha$  becomes smaller, and the supply is reduced<sup>1</sup>. Note that in this model, the supply of natural resources is linked to the consumption behavior.

In Figure 2, the time path of the resource price is shown (path 1). In Figure 2b, we assume a given demand behavior in each period. Markets or the auctioneer set the equilibrium price  $p_0$  and the price will rise in such a way that markets are cleared in each period and over total time. In drawing the time path it has been assumed that both demand elasticities will become larger over time in absolute terms so that the price rise is reduced.

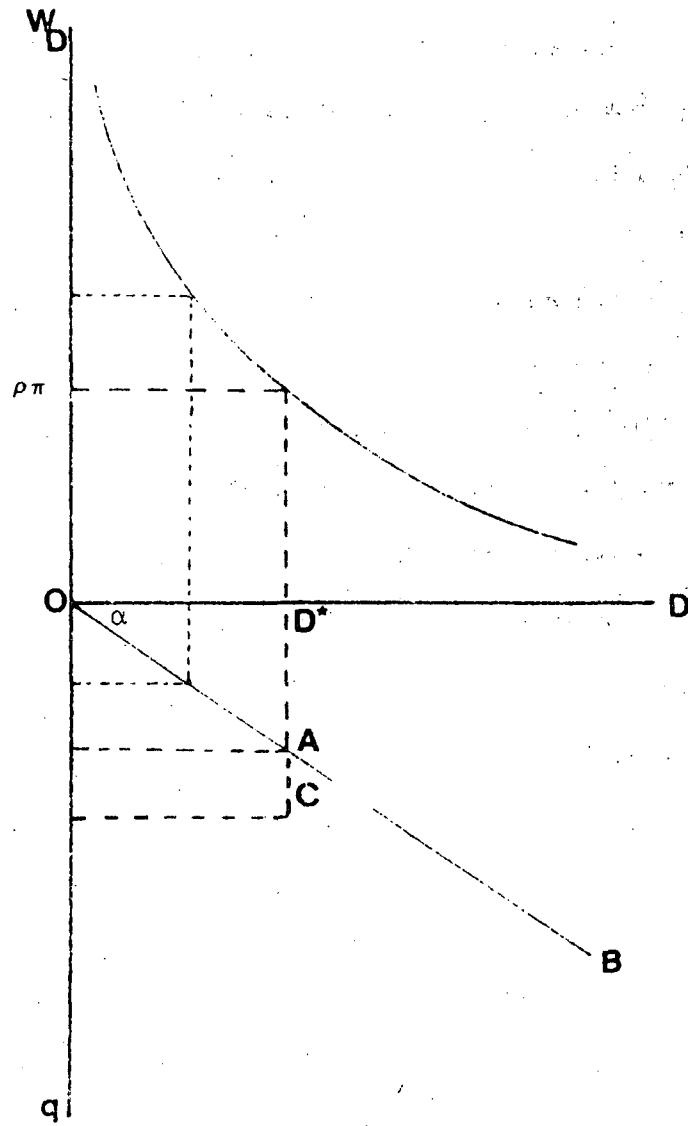


Figure 1

### 3. The Recycling of Hotelling Rents

We now analyze how these results are affected when the resource exporting country can recycle the Hotelling rents and can accumulate foreign capital. In the maximization problem we now have to introduce equation 2b instead of equation 2. Then the Hamiltonian is

$$H = W(D) + \lambda(-q) + \rho(pq - \pi D + rV) \quad (11)$$

We have the following conditions for a welfare maximum

$$\frac{\partial H}{\partial D} = W_D - \rho\pi = 0 \quad \implies \quad W_D = \rho\pi \quad (11a)$$

$$\frac{\partial H}{\partial q} = -\lambda + \rho p = 0 \quad \implies \quad \lambda = \rho p \quad (11b)$$

$$\dot{\lambda} = \delta\lambda - \frac{\partial H}{\partial R} \quad \implies \quad \hat{\lambda} = \delta \quad (11c)$$

$$\dot{\rho} = \delta\rho - \frac{\partial H}{\partial V} \quad \implies \quad \hat{\rho} = \delta - r \quad (11d)$$

Quantities consumed of commodity D continue to be determined by the marginal utility schedule, i.e., equation 5c holds. However, differentiating equation 11b with respect to time and inserting equations 11c and 11d, gives for the change in price

$$\hat{p} = r \quad (12)$$

The change in price of the natural resource is completely determined by the interest rate. Since  $r$  is assumed to be given by the world capital market, the rate of change in the price is given. With given  $\hat{p}$ , the rate of extraction is also determined (compare equation 7). The time profile of extraction is completely independent from the time profile of consumption. This confirms the well-known result that in the presence of perfect capital markets, production (extraction) and consumption decisions are separated (Fisher 1930, Schmalensee 1976, Hoel 1981).

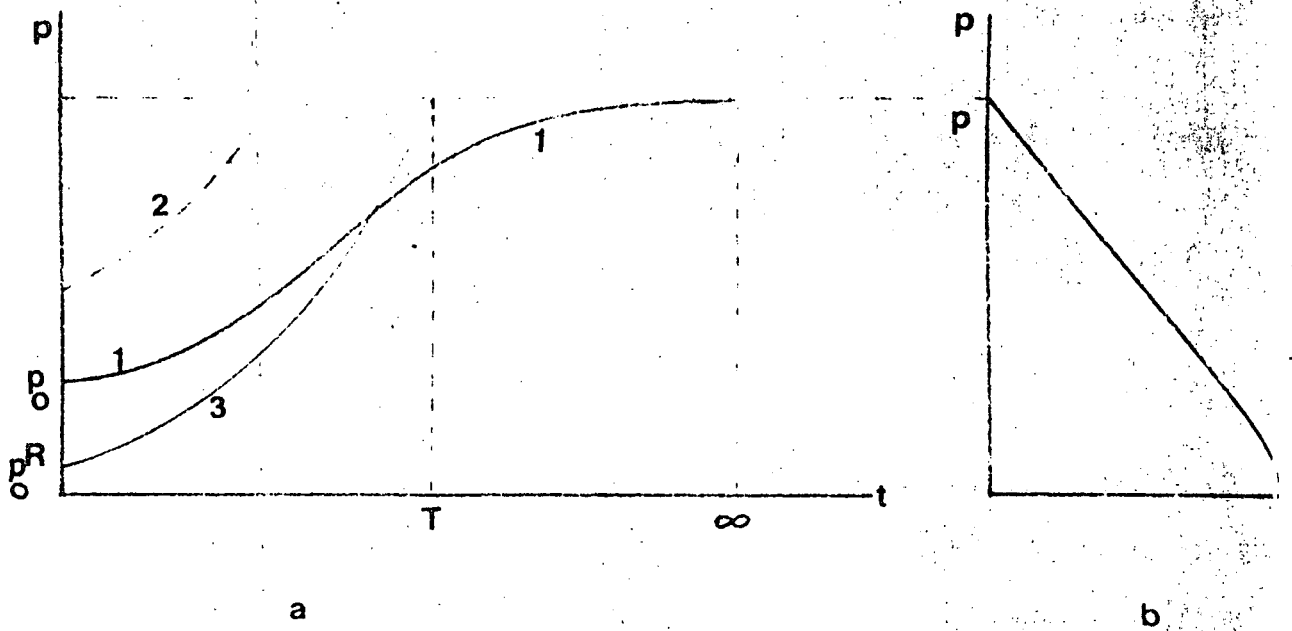


Figure 2



Differentiating equation 11a with respect to time and inserting equation 12 we have

$$\hat{D} = \frac{1}{-\eta} (\delta - r + \pi) \quad (13)$$

so that a rising or a constant price of the imported commodity  $D$  and  $\delta > r$  are sufficient conditions for consumption to decline.<sup>2</sup>

Assume that the resource exporting country does not hold financial assets initially so that  $V_0 = 0$ . For the accumulation of financial capital it is sufficient that in each period<sup>3</sup>

$$pq > \pi D \quad \text{or} \quad p/\pi > D/q \quad (14)$$

where  $p/\pi$  denotes the terms of trade as given by the price system.

Condition 14 requires a positive trade balance. Alternatively, it can be interpreted as a comparative advantage of the resource exporting country with respect to the natural resource if where  $p/\pi$  is the world market price and  $D/q$  is interpreted as the real price of one unit of the resource in terms of the consumption good  $D$  for the resource exporting country.

In Figure 1, consider a single period for which prices  $p$ ,  $\pi$  and  $q$  are given<sup>4</sup>. Then  $q > D\pi/p$  requires that a larger amount of resources is exported than is called for by the balance of trade. Whereas the balance of trade mandates the export of quantity  $D^*A$ , the accumulation of capital commands additional exports  $AC$ .

Assuming  $V_0 = 0$  initially, a sufficient condition for the accumulation of capital is that

$$\frac{\partial(pq)}{\partial t} - \frac{\partial(\pi p)}{\partial t} > 0 \quad (15)$$

so that

$$\frac{pq}{\pi D} r(1 + \epsilon_{qp}) + \frac{1}{\eta} [\delta - r + \hat{\pi}(1 - \eta)] > 0 \quad (15a)$$

Ceteris paribus, financial capital will be built up, the more inelastic is the demand of the resource importing country,  $\epsilon_{qp}$ , the more elastic is the demand of the resource country for its imports, i.e., the lower  $\eta$  and the higher  $\epsilon_{qp}$ , and the higher the time preference with respect to the interest rate,  $\delta > r$ . This last condition implies that initially more weight is put on consumption, but that over time the consumption level is reduced. Equation 15a can be rewritten as

$$r(1 + \epsilon_{qp} + \epsilon_{D\pi}) - \epsilon_{D\pi}(\delta - \hat{\pi}(1 + 1/\epsilon_{qp})) > 0 \quad (15b)$$

If demand of the resource exporting country is elastic, it is sufficient for accumulation to occur that the Marshall-Lerner condition for the normal reaction of the trade balance of the resource importing country is violated. This means that a low demand elasticity of the resource importing country is sufficient for the accumulation of financial capital. From the transversality condition we have that

$$e^{-\delta T} \lambda(T)f(\bar{p}) = e^{-\delta T} [W(D) + \rho(\bar{p}f(\bar{p}) - \pi D + rV)] \quad (16)$$

The present value of the shadow price  $\lambda(T)$  for period T must be greater than zero since the present value for the shadow price must be equal for all periods and a present value shadow price of zero implies no intertemporal scarcity. Since  $q(T) = f(\bar{p}) = 0$ , we must have in terminal time T

$$W[D(T)] - \rho[\pi D(T) - rV(T)] = 0 \quad (16a)$$

Extraction has stopped, i.e.,  $q(T) = 0$ , but consumption continues, i.e.,  $D(T) > 0$  with  $\pi D(T) > rV(T)$ . The country uses its assets to pay for the imports of commodity D.

Note that  $T$  is reached in finite time; however,  $\rho$  cannot reach infinity in finite time so that with  $\pi$  given, we must have from equation 5c that  $\rho > W_D(D) > 0$ ; consequently,  $D > 0$ . Since  $W(D) > 0$ ,  $rV > \pi D$  is excluded, so that  $\dot{V} > 0$  is not possible. After  $T$ , the country does not accumulate financial assets. Also, the country does not perpetuate a situation  $D(T) > 0$  and  $\dot{V} = 0$ . Such a situation clearly violates the transversality conditions since  $W[D(T)] > 0$  does not permit  $rV = \pi D$  with  $\dot{V} = 0$ . However, a situation

$$\dot{V} = rV - \pi D < 0 \quad (16b)$$

can be maintained after  $T$ . According to equation 16b, for given  $r$  and  $\pi$ ,  $V$  declines, and  $D$  must be reduced.  $D$  is steered by equation 11a with

$$\frac{rV}{D} < \frac{W_D(D)}{\rho} = \pi \quad (16b)$$

Of course, in a scenario of rising import prices  $\pi$ , the financial stock melts away more quickly over time. For  $t > T$ , the transversality conditions confirm the separation of the supply of natural resources and the demand for the consumption good.

Thus, the accumulation of financial capital serves as a cushion for the resource exporting country. The accumulation of financial capital separates the problem of optimal consumption and the optimal supply of natural resources. Consumption can continue after extraction has stopped.

Note that our model is a partial equilibrium approach and that a situation  $\dot{V} < 0$  implies the existence of some other activities in the industrialized countries so that they can continue to produce consumption good  $B$  without importing the natural resource  $q$ .

#### 4. The Incidence of Recycling

If recycling is explicitly introduced, the problems of optimal consumption over time and the optimal supply of natural resources are separated. The price rise of the natural resource is completely determined by the given rate of interest so that extraction decisions are independent from consumption decisions of the resource exporting country. Comparing equations 9 and 12, the price of the natural resource will rise faster in the recycling case if

$$r > \frac{\epsilon + \hat{\pi}(1-n)}{1 - n(1 + \epsilon_{qp})} \quad (17)$$

Condition also is obtained by rewriting equation 15a which is sufficient for the accumulation of capital to occur. Thus we have: If recycling takes place, the price of the resource rises faster. Moreover we know that the price rise is constant.

Call  $\hat{p}^R$  the price rise in the recycling case and denote as  $\hat{p}$  the price rise in the case without recycling. Let  $p_0^R$  and  $p_0$  represent the initial prices. Then a faster price increase in the recycling case implies that in the recycling case the initial price must be lower, i.e.,

$$\hat{p}^R > \hat{p} \implies p_0^R < p_0 \quad (17a)$$

This is due to stock equilibrium. Assume that the  $\hat{p}^R$  is greater than  $\hat{p}$  and let  $p_0^R > p_0$  contrary to equation 17a. Then, in the recycling case, a smaller quantity is demanded in the initial period, and, due to the higher price rise, in all other periods. The resource would not be exhausted when  $\bar{p}$  is reached. Consequently, such a time path for  $p$  in the recycling case is not possible, i.e., path 2 in Figure 2 is not permitted. The initial price must be lower in the recycling case. The

time  $\hat{p}^R$ -path (path 3) must intersect the p-path (path 2). Extinction occurs at an earlier date.

We can summarize as follows: The recycling of Hotelling rents represents an incentive to supply more natural resources initially. Recycling introduces a bias in the time profile of extraction in favor of the present generation. Thus, it alleviates scarcity today. The other side of the coin is, however, that the price is rising faster, that extraction in future periods will be smaller, scarcity will be greater in the future and extraction will occur at an earlier date. In this model, the recycling of the Hotelling rents buys time for the non-OPEC nations for substitution, innovation and other adaptations. If these adjustments will not take place, recycling will aggravate scarcities.

##### 5. Potential Extensions

The model presented can be extended in several directions. Instead of welfare maximization, other strategies of the resource exporter can be assumed such as maintaining a given constant permanent real income, determining the highest possible constant consumption path (Hoel 1981), fostering economic development at home (Schmalensee 1976) or maximizing wealth in foreign assets under income restraints (Calvo and Findlay 1978).

It can be assumed that the supply behavior of a large natural resource exporter can squeeze the rate of return in the resource importing countries as is suggested by the macroeconomic evidence in the seventies. Then the induced effect of supply behavior on the rate of return will have a feedback on the supply behavior (Hoel 1981).

Furthermore, it would be interesting to discuss the recycling of Hotelling rents in the context of an international resource cartel (Pindyck 1978, 1981) and under conditions of uncertainty (Pindyck 1980) with respect to demand, or alternative technologies. Finally, government interventions such as import taxes could be introduced (Siebert 1981).

References

- Calvo, G. and R. Findlay, "On the Optimal Acquisition of Foreign Capital through Investment of Oil Export Revenues," Journal of International Economics, Vol. 8 (November 1978), 513-524.
- Clark, Colin W., Mathematical Bioeconomics: The Optimal Management of Renewable Resources, New York: Wiley, 1976.
- Cremer, J. and M.L. Weitzman, "OPEC and the Monopoly Price of World Oil," European Economic Review, Vol. 8 (August 1976), 155-164.
- Dasgupta, Partha S., "Fairness Between Generations and the Social Rate of Discount," Paper presented at the Resources Policy Conference, Oxford, March 1978.
- Dasgupta, Partha S. and Heal, Geoffrey M., Economic Theory and Exhaustible Resources, London: Nisbet, 1979.
- Fisher, Irving, The Theory of Interest, New York: Macmillan, 1930.
- Hnyilicza, Esteban and Robert S. Pindyck, "Pricing Policies for a Two-Part Exhaustible Resource Cartel: The Case of OPEC," European Economic Review, Vol. 8 (August 1976), 129-154.
- Hoel, Michael, "Resource Extraction by a Monopolist with Influence over the Rate of Return on Non-Resource Assets", International Economic Review, Vol. 22 (February 1981), 147-157.
- Hotelling, Harold, "The Economics of Exhaustible Resources," Journal of Political Economy, Vol. 39 (April 1931), 137-175.
- Kemp, Murray C. and Long, Ngo Van (Eds.), Exhaustible Resources, Optimality, and Trade, Amsterdam: North Holland: 1980.

- Pindyck, Robert S., "Gains to Producers from the Cartelization of Exhaustible Resources," The Review of Economics and Statistics, Vol. 60 (May 1978), 238-251.
- Pindyck, Robert S., "The Optimal Production of an Exhaustible Resource When Price is Exogenous and Stochastic," Scandinavian Journal of Economics, 1981, forthcoming.
- Pindyck, Robert S., "OPEC Oil Pricing, and the Implications for Consumers and Producers", M.I.T. Energy Laboratory Working Paper No. MIT-EL-81-045WP, July 1981.
- Schmalensee, Richard, "Resource Exploitation Theory and the Behavior of the Oil Cartel," European Economic Review, Vol. 7 (April 1976), 157-279.
- Siebert, Horst, "Import Taxes and the Intertemporal Supply of Natural Resources", MIT Energy Laboratory Working Paper, No. MIT-EL-81-052WP, August 1981.



Footnotes

1. The diagram can also be used to explain a trade deficit with capital imports ( $\dot{V} < 0$ ) of the resource exporting country.
2. Note that in the case  $\delta < r$ , the shadow price  $p$  will fall,  $D$  may increase, and  $\dot{V}$  can be negative.

3. The change in financial assets is given by

$$\dot{V} = r + \frac{1}{V} (pq - \pi D)$$

4. The assumption of identical prices in the two cases is for explanatory purposes only. An identical price vector in both cases must relate to a different time period.