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## Oil Market Power in General Equilibrium

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# Oil Market Power in General Equilibrium

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## Abstract

We analyze monopoly power in a market for a complementary fossil resource like oil in a two country/two period model with international trade in general equilibrium. Focusing on the complex interplay of capital and resource market, we elaborate how these effects feed back into the resource monopolist's extraction decision. His level of knowledge about the economic structure thereby plays a key role. The accumulation of own capital assets over time, together with a recognized influence of extraction on the interest rate, can lead the monopolist to accelerate or postpone extraction. Considering the interaction of resource market and global capital accumulation poses an incentive for the monopolist to accelerate extraction and to exploit the importers' increased resource addiction in the future. The conservationist bias of resource market power can be increased, dampened or reversed through the general equilibrium effects.

**JEL codes:** D42; D58; D9; Q3

**Keywords:** Monopoly, fossil energy resources, Hotelling rule, general equilibrium, capital market, sovereign wealth

# 1 Resource Monopoly in General Equilibrium

Over two centuries ago, the industrial revolution started when technical developments provided more and more ways to substitute human labor force and animals in production by fossil energy resources. And even after such a long period of unprecedented growth in economic wealth and technological knowledge the availability of fossil energy resources is still seen as a major driving force for economic growth and development in both the industrialized world, as well as in emerging market economies. From an economic perspective, the degree of complementarity between fossil energy resources and other production factors, in particular capital and labor, at the macro level, is still enormous. This is especially true for oil. The lively debates about peak oil, about the heavy dependency of the industrial countries on the supply of oil, and about the drastic consequences of a declining oil supply in the future can be considered as indications of its great influence and importance. The substitutability of oil in the transportation sector, especially with regard to freight and air transport, remains limited, in spite of technological advancements of electric and natural gas engines for passenger cars. Along the same lines, the macroeconomic development and growth paths of big economies and the oil market are naturally treated as strongly interrelated in the debates of market and policy analysts. For instance the oil price peak of 2008 is often explained by the extraordinary growth in emerging markets like China. Overall, reductions in oil supply or increases in the oil price affect the economy so strongly that it is hard to think of any other production input factor or any other market with similarly widespread effects on incomes, prices and expected returns.

To capture these broader effects of oil availability in a consistent model framework we extend the standard partial equilibrium models of resource extraction to a general equilibrium analysis where the overall equilibrium directly depends on the resource extraction path over time. In particular, we are interested in how the influence on the whole economy might feed back into the oil supply decision itself if it is not only implicitly present via equilibrium market prices but explicitly taken into account by oil suppliers. In contrast to a competitive market, this requires the single resource supplier to be able to manipulate and adapt the overall oil supply to his own advantage, so that we assume market power in the resource market. If we think of the geographical concentration of resource stocks and oil suppliers with high market shares such as OPEC, the assumption of resource market power does not seem unrealistic. For simplification – but of course in contrast to the real world oil market – we consider a resource monopolist instead of an oligopolistic (or competitive fringe) market structure.

Combining these two aspects, the broader economic relevance of the resource in question and market power in the resource market, raises the more general question of how a resource monopolist might act in general equilibrium. Like the usual textbook monopolist, a resource monopolist takes into account the price and demand changes he induces with his supply behaviour. But since the resource is exhaustible, the monopolist optimizes supply not only for one period, as in a static model, but simultaneously for all future periods up to exhaustion of his resource stock considering opportunity costs of restrictions in period supply and following the classical Hotelling rule (cf. Dasgupta and Heal (1979) or Stiglitz (1976)).

In general equilibrium, however, the investment returns, the capital accumulation dynamics, the future factor demand and future price reactions to changes in supply are not exogenously given, but generally dependent on the specific equilibrium outcome, which in turn is directly influenced by the monopolist's supply decision. When analyzing a resource monopolist's strategic behavior while at the same time extending the standard partial equilibrium framework, it is therefore of key importance to consider the monopolist's level of awareness of oil's prominent role and its overall effects on the world economy. In principle, this holds true for every monopolist in general equilibrium. However, given the widely recognized importance of oil, we believe that it is especially plausible for an oil supplier with market power to realize at least some of the widespread effects of his supply decision. With our paper we want to create a better and more realistic understanding of the behavior of an oil supplier with market power and far-reaching influence compared to the standard Hotelling rule in partial equilibrium, not least contributing to the design of more effective climate policy instruments.

We introduce a general equilibrium framework with a finite time horizon of two periods that mainly differs from the conventional partial equilibrium setting in resource economics by including a capital market with an endogenous accumulation of physical capital from the first to the second period, since the endogenous capital stock dynamics constitute the pivot of the various general equilibrium effects. Moreover, in a two country setting we reproduce the typical asymmetry in resource endowments and production technologies between resource exporting and importing countries where the resource-rich country does not have any consumption good to sell apart from the natural resource and where it "just" fuels the production and growth processes in the resource importing country. As a consequence, the resource exporter transforms his resource wealth into financial wealth to finance current consumption and to build up a capital asset stock for future consumption. Due to the lack of investment options at home, these funds are invested abroad. However, as we assume a perfect and competitive

international capital market with globally uniform returns, we do not need to specify where the capital savings of resource-exporters are invested. Real exporting countries of fossil energy resources often dispose of considerable sovereign wealth funds following the same logic. The funds of the United Arab Emirates (\$ 1,078.5 billion) and Saudi Arabia (\$ 757 billion) being the two biggest such sovereign asset stocks among OPEC countries (Sovereign Wealth Fund Institute (2014)). Beyond official sovereign wealth funds, all other kinds of petrodollar bank deposits are invested in some manner in the capital market, very often in the industrialized countries.

From the linkage between resource supply and the capital market in general equilibrium in our model follows that the resource-exporting country will have a direct influence on the return of its accumulated capital funds. In contrast to Hillman and Long (1985), this influence runs only via resource market power and explicitly not by assuming that the resource monopolist has additionally capital market power. One of the most striking results of our general equilibrium approach is this inherent new role of capital assets in the resource monopolist's strategy once he realizes that his oil supply has an influence on the interest rate and the growth path (see sections 3.3 and 3.5.1).

On the one hand, this may be interpreted as an extension of conventional resource market power. On the other hand, the dependency of capital returns on the availability of resources constrains the resource exporter when he tries to exert market power in the resource market. The often discussed dependency of the oil importers on the "goodwill" of key resource exporting countries therefore may not be as unilateral as expected at first, but in fact mutual. In any case, recognizing his influence on the return of petrodollar capital funds partly shifts the resource exporter's focus from the resource rents which he can receive from the resource-importing countries to their economic performance.

In the following, we start by comprehensively introducing and interpreting the general equilibrium framework. Since we aim to derive and interpret the optimal extraction policy depending on the monopolist's state of awareness of the overall economic structure, we first describe a conditional equilibrium, which solely depends on the extraction path the monopolist chooses. Next, we vary the monopolist's awareness of the transmission channels of resource supply into the capital market in four steps. In scenario  $N$  ('naive') the monopolist's knowledge is that of a partial equilibrium monopolist. In scenario  $NA$  ('naive + assets') awareness of his influence on the interest rate and the resulting capital asset motive is added to the monopolist's considerations. In scenario  $G$  ('general equilibrium knowledge') the monopolist knows about the capital stock dynamics and

uses this knowledge in his strategic 'addiction motive', while the asset motive of scenario *NA* is excluded again. Finally, in scenario *GA* ('general equilibrium knowledge + assets') all previous aspects and levels of awareness are taken and analyzed together.

For each scenario, we derive a modified Hotelling rule or intertemporal non-arbitrage condition which characterizes optimal resource supply over time. We compare these different optimal extraction scenarios analytically, also with the standard monopoly case, to gain intuition on the impact of the general equilibrium feedback effects and on the impact of the specific level of awareness on optimal extraction. Since different supply policies will not only lead to different extraction paths, but also to different equilibrium outcomes, a full analytical comparison of all the scenarios is, however, not feasible. To resolve these analytical ambiguities we employ a numerical simulation of the model, which allows us to graphically illustrate the different scenarios and to derive quantitative results. Finally, we shortly discuss the role of changes in the elasticity of substitution between capital and the resource, which may be interpreted as a measure of input efficiency in production and thereby of technological development.

For our analysis we take into account and build upon previous steps in the literature from partial equilibrium to general equilibrium analysis of exhaustible resource extraction and supply. While Hoel (1981) introduced an influence of a resource monopolist's decision on the interest rate, this influence was still postulated in an otherwise partial equilibrium model and unspecified, disregarding the associated capital stock dynamics. Hassler et al. (2010) also incorporate an influence of the resource supplier on the capital returns, but lack the intertemporal optimization of supply. Hillman and Long (1985) bring forward a general equilibrium model, where the interest rate is freely chosen by a resource exporter with market power on both, the resource and the capital market. However, their model lacks the impact channel from resource extraction on the interest rate directly over the physical production function, as well as the corresponding effect of the capital stock dynamics on the interest rate over the production function and all resulting repercussions. Thus, they leave this aspect of complementarity between oil and physical capital in production out of the picture. Moreover, it's exactly their exporter's free choice of the interest rate as an additional independent variable that excludes the effects of resource supply behavior on the capital market (and the corresponding consequences), that naturally arise in our general equilibrium framework and that we are interested in, from their model. Moussavian and Samuelson (1984) incorporate an exhaustible resource monopolist's influence on the capital accumulation in their model. Our analysis of scenario *G* is consistent with this study and develops it further, drawing additional conclusions. Besides the studies mentioned above, how-

ever, a resource monopoly is usually, from Stiglitz (1976) to Fischer and Laxminarayan (2005), analyzed with an exogenous and constant interest rate, as far as we know.

Gaitan et al. (2006) also see the necessity for dynamic general equilibrium models and propose an own such contribution. But they focus on the case of isoelastic resource demand in a competitive resource market, not more general resource demand and monopoly power. Van der Meijden et al. (2014) propose a two-country general equilibrium setup, which is in many ways similar to ours, for the analysis of resource and capital taxation effects with a focus on the Green Paradox. Their model features perfect competition on the resource and capital markets, in contrast to our resource monopoly. Long and Stähler (2014) also establish a dynamic general equilibrium model in perfect competition: Their focus lies on the effects of technological change on the interest rate and the consequences for the Green Paradox, i.e. a different effect channel on the interest rate than the one we are looking at.

We start by introducing the model framework and by deriving equilibrium relationships conditional on the chosen resource supply path in section 2. In section 3, we analyze the optimal supply decision of a resource monopolist by distinguishing different scenarios according to the monopolist's level of awareness of the overall economic structure and the widespread effects of his supply decision. We present a visualization of the analytical results by use of an exemplary numerical simulation of the model in section 4 and briefly discuss the crucial importance of the elasticity of substitution in section 5. Section 6 concludes.

## 2 Model

We consider a general equilibrium framework with two countries  $m = E, I$  and a finite time horizon of two periods  $t = 1, 2$ . In each country, there is a representative household deriving utility from consuming a final good which we choose as numeraire. Households have symmetric homothetic preferences represented by the life-time utility function

$$U(c_{1m}, c_{2m}) = u(c_{1m}) + \beta_m u(c_{2m}) = \begin{cases} \frac{c_{1m}^{1-\eta}}{1-\eta} + \beta_m \frac{c_{2m}^{1-\eta}}{1-\eta} & \text{for } \eta \neq 1, \eta > 0 \\ \ln c_{1m} + \beta_m \ln c_{2m} & \text{for } \eta = 1 \end{cases} \quad (1)$$

where  $1/\eta$  equals the constant elasticity of intertemporal substitution and  $\beta_m < 1$  denotes the utility discount factor for country  $m = E, I$ . For symmetric countries, we

have  $\beta_E = \beta_I$ .

## 2.1 Resource Extraction

Country  $E$  owns the entire global stock of a scarce fossil resource  $\bar{R} = R_1 + R_2$  which is always exhausted after both periods. Resource extraction is costless and controlled by an authority which we call the “sheikh”, who benevolently distributes resource income

$$\pi_{tE} = p_t R_t \quad (2)$$

to the representative household in country  $E$ , with  $R_t$  being the resource supply and  $p_t$  denoting the resource price.

## 2.2 Final Goods Production

In the block of resource-importing countries  $I$ , there is a competitive final goods production sector. Final goods are produced by use of three input factors, capital  $K_t$ , resources  $R_t$  and labour  $L_t$  which is in constant supply from the representative household. We assume a CES production technology

$$F_t = F(K_t, R_t) = A [\gamma K_t^\alpha + \lambda R_t^\alpha + (1 - \gamma - \lambda) L^\alpha]^\frac{1}{\alpha} \quad (3)$$

where  $-\infty < \alpha < 1$ . The parameter  $A > 0$  measures total factor productivity, and the constant elasticity of substitution between the two variable input factors is given by

$$\sigma = -\frac{d \ln \left( \frac{K_t}{R_t} \right)}{d \ln \left( \frac{F_{tK}}{F_{tR}} \right)} = \frac{1}{1 - \alpha} > 0$$

The CES technology has constant returns to scale but decreasing returns to scale with respect to the only variable production inputs capital and oil. With profit maximizing competitive final goods producers the first-order conditions for optimal factor use (implicitly) define the market demand for the resource and capital as functions of both, the consumer resource price  $p_t$  and the capital cost/return  $i_t$ . From labour supply, the representative household earns labour income which derives from the residual profits

$$\pi_{tI} = F_t - p_t R_t - i_t K_t \quad (4)$$



## 2.3 Capital Supply

For the first period, there is an exogenously given capital endowment  $s_{0m}$  to households in both countries  $m = E, I$  which is used in final goods production. We therefore have

$$K_1^s = s_{0E} + s_{0I} \quad (5)$$

Second period capital supply derives from the aggregated but endogenous savings of households in both countries which do not add to the first period capital stock  $K_1$ . Instead, the existing capital stock is available for consumption (and savings) at the end of each period without depreciation. Positive capital accumulation therefore implies that  $s_{1E} + s_{1I} > K_1$ . The respective household has rational expectations and chooses savings as to maximize its life-time utility (1) subject to country-specific budget constraints.

In country  $I$ , the household takes current and future labour income, the market interest rates  $i_1$  and  $i_2$  as given. Its budget constraints therefore are

$$c_{1I} = y_{1I} - s_{1I} \quad (6)$$

$$c_{2I} = \pi_{2I} + (1 + i_2)s_{1I} \quad (7)$$

where  $y_{1I} = \pi_{1I} + (1 + i_1)s_{0I}$  denotes the first period income stream and  $\pi_{2I}$  the second period income stream which both are exogenous to the savings decision. We concentrate on the value added tax case and explicitly point out where a unit resource tax would have different implications. For the most part, the unit resource tax case is, however completely analogue.

In country  $E$ , the representative household earns income from capital endowment and from resource revenue so that the budget constraints for both periods are given by

$$c_{1E} = y_{1E} - s_{1E} \quad (8)$$

$$c_{2E} = \pi_{2E} + (1 + i_2)s_{1E} \quad (9)$$

where again  $y_{1E} = \pi_{1E} + (1 + i_1)s_{0E}$  denotes first period income exogenous to the savings decision and  $\pi_{2E}$  from (2) resource revenue.

For given period income streams and a given interest rate  $i_2$ , optimal savings  $s_{1m} =$

$s_{1m}(y_{1m}, \pi_{2m}, i_2)$  in both countries are implicitly defined by the respective Euler equation

$$\frac{u'(c_{1m})}{\beta_m u'(c_{2m})} = 1 + i_2 \quad (10)$$

as a function

$$s_{1m} = s_{1m}(y_{1m}, \pi_{2m}, i_2) \quad (11)$$

Since we assume homothetic consumption preferences, the marginal savings propensities with respect to changes in period incomes are independent of the wealth of the household but are determined by the discount factor  $\beta_m$ , the intertemporal elasticity of substitution  $\frac{1}{\eta}$  and the market interest rate  $i_2$  only. The savings reaction to marginal changes in the interest rate generally is of ambiguous sign due to the counteracting income and substitution effect induced. Moreover, due to  $\pi_{2m}$  from (7) and (9) respectively it obviously depends on the distribution of resource remuneration between both countries.

Given that the resource constraint holds, second period capital supply from aggregated savings can be represented as a function of the resource supply path and the interest rate  $i_2$  only for *symmetric* ( $\beta_E = \beta_I$ ) and homothetic preferences ( $K_2^s = K_2^s(R_2, i_2)$ ). A shift of resources to the future period decreases capital supply because it implies a transfer of final goods production and thereby aggregate (world) income from the first to the second period *ceteris paribus*. This redistribution of income creates a disincentive to save. In contrast, aggregate savings unambiguously increase with a rise in the interest rate  $i_2$ . The ambiguity of the single household's savings reaction to an increase in the interest rate vanishes because the income effects which a higher interest rate induces for given savings in both countries are exactly compensated by the loss in labour income in country *I* from higher capital costs in final goods' production.

## 2.4 Conditional Market Equilibrium

In the following, we characterize the market equilibrium in all three markets, the resource market, the capital market and the market for final goods conditional on the resource supply path, i.e. given *any* allocation of resources to both periods that fulfills the binding resource constraint. The optimal resource supply for the sheikh controlling resource extraction in country *E* is derived later on. To this end, we also analyze the comparative statics of this conditional market equilibrium with respect to changes in

the resource supply path. This gives us the actual (general equilibrium) market reaction to the supply decision which the resource monopolist takes into account if he has full level of information of the entire economic structure. The resource market equilibrium is characterized by the market clearing condition

$$R_t^d(p_t, i_t) = R_t^s \quad \text{for both periods } t = 1, 2 \quad (12)$$

for resource demand derived from competitive final goods production and in conjunction with the binding resource constraint. With fixed capital supply from aggregate endowments the capital market equilibrium condition in both periods therefore reads

$$K_t^d(i_t, p_t) = K_t^s(R_t, i_t) \quad (13)$$

with  $K_1(i_1, p_1) = s_{0E} + s_{0I}$  and capital demand also deriving from competitive final goods production.

**Final Goods Market:** In equilibrium, aggregate consumption (and savings) of final goods has to equal aggregate consumption possibilities which are given from production and the capital stock in both periods:

$$\begin{aligned} c_{1E} + c_{1I} + K_2 &= F_1(K_1, R_1, L) + K_1 \\ c_{2E} + c_{2I} &= F_2(K_2, R_2, L) + K_2 \end{aligned}$$

If the resource and the capital market are in equilibrium, the market for final goods must be in equilibrium, too, due to Walras' law.

**Comparative Statics of the Conditional Market Equilibrium:** We now consider the dependency of the conditional market equilibrium laid out before on the resource supply path chosen. The conditional equilibrium is, in particular, characterized by equilibrium factor market prices in both periods and the equilibrium second period capital stock. Thus, we are interested in how the equilibrium market prices for the resource  $p_t$  and capital  $i_t$  as well as capital accumulation  $K_2$  depend on the resource supply path, i.e. on shifts of resources from one period to the other given that the resource constraint binds.

From the total derivative of (13) and (12) we observe that

$$\frac{dp_1}{dR_1} = \frac{\partial p_1}{\partial R_1} = F_{1RR} < 0 \quad (14)$$

due to the concavity of the production technology and

$$\frac{di_1}{dR_1} = \frac{\partial i_1}{\partial R_1} = F_{1KR} > 0 \quad (15)$$

by the complementarity of capital and resources in production. For the second period, we get from totally differentiating (13) and (12) and solving for the induced change in the equilibrium market prices <sup>1</sup>

$$\frac{dK_2}{dR_2} = \frac{\frac{\partial s_{1E}}{\partial \pi_{2E}} p_2 - \frac{\partial s_{1E}}{\partial y_{1E}} p_1 + F_{2KR} SE}{1 - F_{2KK} SE} \quad (16)$$

where  $SE$  again denotes the aggregated substitution effect from a change in the interest rate  $i_2$ .

The denominator captures the feedback effect of a change in the second period capital stock on savings incentives. A higher capital stock  $K_2$  decreases ceteris paribus the marginal productivity of capital due to the concavity of the production technology (3) and thus the interest rate  $i_2$  in capital market equilibrium, which induces households to substitute savings for present consumption.<sup>2</sup> Due to the concavity of the production technology and the positive substitution effect  $SE$ , the denominator is unambiguously positive.

The numerator in (16) measures the influence of a shift of resources to the future period on savings incentives. First, a reallocation of resources from the first to the second period shifts ceteris paribus production and thereby aggregate income to the future period. Second, by the complementarity of resources and capital in production a higher future resource supply ceteris paribus boosts the marginal productivity of capital which translates into a higher capital return in market equilibrium ( $F_{2KR} = \frac{\partial i_2}{\partial R_2} > 0$ ). This again induces a substitution effect which unambiguously increases the savings

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<sup>1</sup>We simplify notation by using

$$\frac{\partial s_{1E}}{\partial i_2} + \frac{\partial s_{1I}}{\partial i_2} - \frac{\partial s_{1I}}{\partial \pi_{2I}} K_2 = SE$$

in case of symmetric preferences as we showed above.

<sup>2</sup>Recall that the income effects induced in both countries by this decrease in the interest rate exactly offset each other in case of symmetric and homothetic consumption preferences.

incentives in both countries. Thus, the overall reaction of capital accumulation to a postponement of extraction is ambiguous, in general. Here we concentrate for intuitive reasons on the case where the savings disincentive from the intertemporal transfer of aggregate income to the second period dominates the induced substitution effect so that there is a negative relationship between the postponement of extraction and the second period capital accumulation. A sufficient condition for this to hold is

$$\sigma \geq \frac{1}{\eta}$$

i.e. the elasticity of substitution between capital and oil in final goods production must not be lower than the intertemporal elasticity of substitution. If  $\sigma > \frac{1}{\eta}$ , shifting resources to the second period lowers the resource price and thereby capital demand so much that the strong reduction of capital demand outweighs the incentive to increase savings from the complementarity driven rise of the interest rate  $i_2$ .

Given (16) the equilibrium change in the resource consumer price is

$$\frac{dp_2}{dR_2} = \frac{\partial p_2}{\partial R_2} + \frac{\partial p_2}{\partial K_2} \frac{dK_2}{dR_2} = F_{2RR} + F_{2RK} \frac{dK_2}{dR_2} < 0 \quad (17)$$

where the negative sign holds irrespective of the sign of  $\frac{dK_2}{dR_2}$ . This implies that the direct own price effect  $\frac{\partial p_2}{\partial R_2}$  always outweighs the indirect price effect from the endogeneity of capital accumulation. Analogously, the equilibrium change in the interest rate can be decomposed

$$\frac{di_2}{dR_2} = \frac{\partial i_2}{\partial R_2} + \frac{\partial i_2}{\partial K_2} \frac{dK_2}{dR_2} = F_{2KR} + F_{2KK} \frac{dK_2}{dR_2} > 0 \quad (18)$$

where again the direct complementarity driven effect always outweighs the indirect effect of the resource supply path change so that the positive relationship holds irrespective of the sign of  $\frac{dK_2}{dR_2}$ . This independence of the market price reactions of the sign of  $\frac{dK_2}{dR_2}$  is at least true as long as we assume symmetric (homothetic) preferences, i.e.  $\beta_E = \beta_I$ .

### 3 The Resource Monopolist's Optimal Extraction Path

In section 2 we characterized the general equilibrium of the model conditional on the monopolist's resource supply decision, in particular by deriving the resource price reac-

tion (18) and the interest rate reaction (17) to changes in the resource extraction path. We now turn to the optimal resource supply decision of the monopolist, i.e. of country  $E$ , to characterize and interpret the overall (and no longer conditional) equilibrium of the model.

In a standard partial equilibrium setting, a monopolist exerts market power typically by choosing supply for a given (inverse) demand curve as to maximize his objective function. In a general equilibrium setting, the level of awareness of the economic structures therefore will determine what the monopolist considers optimal. For example, it depends on the monopolist's level of awareness whether he takes into account the overall general equilibrium resource price effect (17) of his supply decision or whether he neglects the feedback via the capital market and just accounts for the standard (partial) reaction of the resource price. Note that the additional general equilibrium transmission effects are still present and still influence the equilibrium outcome, even if the monopolist is not explicitly aware of them. In this case, the monopolist just cannot actively use them to his own advantage but observes equilibrium outcomes like a price taker in a competitive market.

In the following, to assess the importance of the various aspects of the monopolist's knowledge for optimal resource supply, we change his scope of information about the structure of the world economy, i.e. about various effects of resource supply that are introduced via the endogeneity of the capital market equilibrium and future resource demand. We start by deriving the characterization of optimal resource supply if the monopolist is indeed aware of the overall economic structure so that he realizes and internalizes all the widespread effects of his supply decision in general equilibrium. Given this overall equilibrium, we analyze how the equilibrium outcome will change as soon as we restrict the monopolist's awareness. Due to the additive structure of the first order condition that characterizes optimal resource supply, we can directly link assumptions about the monopolist's awareness of single effects to specific terms in the first order condition. Therefore, apart from the full knowledge scenario, we can distinguish three different scenarios by suppressing the corresponding terms in the first order condition for optimal resource supply.

First (scenario  $N$ ), we consider a monopolist who only accounts for the resource market's specific effects of his extraction decision, just as in a conventional partial equilibrium framework. Second (scenario  $NA$ ), the monopolist is still assumed to base his overall supply decision on partial equilibrium information but now he knows about the production side/technology in the resource importing country. Hence, the monopolist is

	<b>Without Capital Assets</b>	<b>With Capital Assets</b>
<b>Partial Equilibrium Thinking</b>	<i>Scenario N:</i> Naive Monopolist	<i>Scenario NA:</i> Naive Monopolist with Asset Motive
<b>General Equilibrium Thinking</b>	<i>Scenario G:</i> General Equilibrium Monopolist (Oil Addiction Motive)	<i>Scenario GA:</i> General Equilibrium Monopolist with Asset Motive (Omniscient Monopolist)

Table 1: Overview over the four scenarios

aware of the complementarity of fossil resources and capital in final goods production and thereby of the positive and instantaneous impact of resource supply on the return on capital assets. This enables the monopolist to pursue a so called asset motive as a second strategic motive of exerting market power in addition to the standard own price effect on infra-marginal resource units sold. In a third scenario (scenario *G*), the monopolist recognizes the influence of the resource extraction path on the accumulation of capital and the dependency of future resource demand on the capital stock from which the so called addiction motive may arise. At the same time and in contrast to the second case *NA*, we assume that the monopolist does not understand his influence on the interest rate. By isolating the different strategic motives of resource extraction – the asset motive and the addiction motive – this differentiation allows us to compare the equilibrium outcomes and thereby analyze the fully informed monopolist’s extraction decision more intuitively. Scenario *GA* is then the full general equilibrium knowledge without any suspended terms. An overview over the scenarios is presented in table 1.

### 3.1 Optimal Resource Supply: Full General Equilibrium

Think of a sheikh<sup>3</sup>, who controls resource extraction in country *E* and benevolently distributes resource revenues (2) back to his people. The sheikh as a benevolent planner knows about the households’ consumption preferences (1) and savings behavior as characterized by (10) and is fully aware of the economic structure of the world economy.

<sup>3</sup>or any other benevolent authority in country *E*.

Given these assumptions, the benevolent sheikh chooses the resource supply path  $(R_1, R_2)$  as to maximize life-time utility of the representative household in country  $E$  (1)

$$\max_{R_1, R_2} U(c_{1E}; c_{2E}) = u(c_{1E}) + \beta u(c_{2E}) = \frac{c_{1E}^{1-\eta}}{1-\eta} + \beta \frac{c_{2E}^{1-\eta}}{1-\eta}$$

Thereby, the sheikh has to obey the binding resource constraint and knows about the budget constraints of the representative households in both countries. Due to his level of awareness and information, the omniscient monopolist also explicitly takes into account that the conditional market equilibrium from section 2.4 holds. More specifically, the sheikh is aware of the total influence of his resource supply on the conditional market equilibrium. Following the concept of the familiar monopoly model, the sheikh therefore accounts not only for the partial resource price change but for the reactions of factor market prices in conditional equilibrium in both periods.

The overall optimal extraction path from the sheikh's perspective, is then characterized by the first-order condition

$$\begin{aligned} u'(c_{1E}) \left[ - \left( p_1 + \frac{\partial p_1}{\partial R_1} \right) - \frac{\partial i_1}{\partial R_1} s_{0E} - \frac{ds_{1E}}{dR_2} \right] \\ + \beta u'(c_{2E}) \left[ p_2 + \frac{dp_2}{dR_2} R_2 + s_{1E} \frac{di_2}{dR_2} + (1 + i_2) \frac{ds_{1E}}{dR_2} \right] = 0 \end{aligned}$$

The sheikh only has an indirect influence on savings via his extraction policy as households in country  $E$  separately decide on savings given some distribution of period incomes  $y_{1E}, \pi_{2E}$  (exogenous to the savings decision) and the interest rate  $i_2$ . The latter implies, however, that the Euler equation (10) will hold for any distribution of period incomes and any interest rate in equilibrium and therefore for any resource extraction path. Thus, we can substitute for the marginal utilities from the Euler equation and finally characterize optimal resource supply as

$$(1 + i_2^{GA*}) MR_1^{GA*} = MR_2^{GA*} \quad (19)$$

where we define the marginal resource value from the sheikh's perspective – the modified marginal resource revenue – if he is fully informed about the underlying economic structure as

$$MR_t^{GA} = MR_t^{GA}(K_t, R_t) = p_t + \frac{dp_t}{dR_t} R_t + \frac{di_t}{dR_t} s_{(t-1)E} \quad (20)$$



In the first period, the factor market price reactions to a change in resource supply are given by the partial effects  $\frac{dp_1}{dR_1} = \frac{\partial p_1}{\partial R_1} = F_{1RR}$  and  $\frac{di_1}{dR_1} = \frac{\partial i_1}{\partial R_1} = F_{1KR}$  as the capital stock  $K_1$  is exogenously given. For the second period, the sheikh, due to his comprehensive level of awareness, takes into account the total change in factor prices in equilibrium as defined by (18) and (17).<sup>4</sup> Given that households always will save optimally, the resource extraction policy cannot increase life-time utility of households in country  $E$ , in line with the Envelope theorem. We may interpret condition (19) as a modified Hotelling rule for an omniscient monopolist in general equilibrium. The optimal equilibrium extraction path that is implicitly defined by (19) is denoted as  $(R_1^{GA*}, R_2^{GA*})$  and correspondingly all equilibrium variable values for this scenario are labeled with “ $GA^*$ ”.

Alternatively, we could consider the benevolent sheikh as an omnipotent social planner *for country E* if the sheikh is assumed to make the savings decision on his own instead of taking the households’ decision as given. However, since households also have perfect foresight and in equilibrium always save optimally according to (10) for any extraction path, the social planner could not improve the outcome of the benevolent sheikh. Note that this holds true as long as the planner cannot exert market power in the capital market by his savings decision. However, to focus just on the effect of resource market power we explicitly excluded capital market power. For an analysis of a resource monopolist with additional capital market power in general equilibrium see Hillman and Long (1985).

In the following we will develop the interpretation of the modified Hotelling rule (19) and the corresponding extraction path from the discussion of different scenarios where the sheikh is constrained in his awareness of some or all of the more widespread effects of his supply decision in the general equilibrium framework at hand.

### 3.2 Scenario N: A ‘Naive’ Monopolist

We start with the most restrictive scenario. Assume that the sheikh does not realize the more widespread effects of his supply decision at all. The sheikh is “naive” (Moussavian and Samuelson (1984)) in the sense that he completely neglects the endogeneity of capital accumulation and second period resource demand and their dependency on the resource extraction path he directly chooses. Instead, the sheikh takes the second period

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<sup>4</sup>Note that these equilibrium reactions hold for changes in the overall extraction path, i.e. only for an intertemporal reallocation of the given resource stock, and cannot be interpreted for an isolated increase in second period resource supply.

capital stock  $K_2$  and thereby resource demand as exogenously given for both periods and consequently also does not recognize the influence of resource supply on the interest rate  $i_t$  for periods  $t = 1, 2$ . With these assumptions the sheikh effectively has a conventional partial equilibrium thinking. Since from the naive sheikh's perspective  $\frac{dK_2}{dR_2} = 0$  and  $\frac{di_2}{dR_2} = 0$  in (19), the optimal resource supply is characterized by the condition

$$(1 + i_2^{N*})MR_1^{N*} = MR_2^{N*} \quad (21)$$

for given capital stocks  $K_1$  and  $K_2$ , where we define

$$MR_t^N = MR_t^N(K_t, R_t) = p_t + \frac{\partial p_t}{\partial R_t} R_t = \frac{p_t}{\sigma} [\theta_{tR} - (1 - \sigma)] \quad (22)$$

The last transformation holds for the CES production technology (3) in resource market equilibrium and  $\theta_{tf} = \frac{F_{tf}f}{F_t}$  denotes the share of total output which factor  $f$  captures as remuneration.

Maximizing life-time utility of the representative household by choice of the resource extraction path is equivalent to maximizing the present-value of life-time income for the household, as the sheikh does not take into account the additional effects of resource supply on households' period income via the interest rate and on the capital stock. We could equivalently assume that the resource is extracted by a private firm in country  $E$ .<sup>5</sup>

Condition (21) requires an increase in the marginal value of the resource. The general equilibrium transmission channels influence the equilibrium outcome so that this increase may derive from the resource supply pattern over time as well as from the change in the capital stock, or a combination of both. Due to the concavity of the CES technology from (3), we have

$$\left. \frac{\partial MR_t^N}{\partial R_t} \right|_{K_t} = \frac{2 - \sigma}{\sigma} \left[ \theta_{tR} - \frac{1 - \sigma}{2 - \sigma} \right] \frac{\partial p_t}{\partial R_t} < 0 \quad \text{for all } \sigma > 0 \quad (23)$$

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<sup>5</sup>In fact, from maximizing the present value of resource revenues  $\pi_{tE}$

$$\max_{R_2} \pi_{1E} + \frac{\pi_{2E}}{1 + i_2} \quad \text{s.t. } R_1 = \bar{R} - R_2$$

again condition (25) follows for *given* resource demand functions and a *given* second-period market interest rate  $i_2$ , i.e. for a naive private monopolist with perfect foresight. This equivalency also arises in Hillman and Long (1985) where in contrast to the model at hand the supply and savings decisions are not made separately by two distinct agents but by the authority controlling the resource supply.

and

$$\left. \frac{\partial MR_t^N}{\partial K_t} \right|_{R_t} = \frac{F_{tRK}}{F_{tRR}} \left. \frac{\partial MR_t^N}{\partial R_t} \right|_{K_t} > 0 \quad \text{for all } \sigma > 0 \quad (24)$$

given that the monopolist has chosen supply such that  $MR_t^N > 0$ .<sup>6</sup>

### 3.2.1 Comparison with Perfect Competition

In the following, we analyze the naive monopolist's solution in more detail by comparison with the competitive outcome. Since an explicit solution for the optimal supply path defined by the modified Hotelling rule is generally not feasible, we first hold the capital stock fixed and focus on the effect of market power. In the next section, we consider the influence of capital accumulation on the optimal extraction path both for the monopolistic and the competitive case in more detail.

Without capital accumulation – the special case of a fixed capital stock  $K_1 = K_2$  in our model framework – the inverse demand  $p_t(K_t, R_t)$  is given by the same function for *both* periods. Moreover, for the comparison with the competitive outcome, it proves useful to rearrange the naive monopolist's solution (21) to

$$1 + i_2^{N*} = \frac{MR_2^N(K_2, R_2^*)}{MR_1^N(K_1, R_1^*)} \quad (25)$$

For constant capital stocks we know from (23) that condition (25) can only be met for a decreasing resource supply path. In fact, by holding the capital stock constant, we effectively replicate the well-known partial equilibrium analysis of monopolistic resource supply (see Stiglitz (1976)).

In the competitive market equilibrium, the overall market extraction path  $(R_1^{C*}, R_2^{C*})$  is characterized by the Hotelling condition (see e.g. Dasgupta and Heal (1979))

$$1 + i_2^{C*} = \frac{p_2(K_2, R_2^{C*})}{p_1(K_1, R_1^{C*})} \quad (26)$$

Comparing both Hotelling conditions for constant capital stocks reproduces the results of Stiglitz (1976): With a constant capital stock over time the monopolist will

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<sup>6</sup>For  $MR_t^N \leq 0$ , the resource would not be scarce at least from the monopolist's perspective. In this case, the given resource stock would no longer constrain the monopolist in his supply decision over both periods and the dynamic setting effectively would be reduced to the static case where profit maximization without production costs always leads the monopolist to supply such that  $MR_t^N = 0$ .

choose a more (less) conservationist extraction path compared to the competitive market outcome if  $\sigma < 1$  ( $\sigma > 1$ ). For iso-elastic demand or  $\sigma = 1$ , the monopolistic and competitive extraction path coincide.

Even though both the monopolist and competitive resource suppliers will completely exhaust the resource stock and thereby choose the same total market supply if the resource is indeed scarce, the speed of extraction may differ due to the resource market power. In fact, the growth of the marginal resource revenue in the monopolistic equilibrium generally does not only derive from the growth of resource market prices over time as for the competitive case, but also from changes in the price elasticity of resource demand  $\epsilon_{R_t, p_t}$ . This can be observed by rearranging marginal resource revenue  $MR_t^N$  to

$$MR_t^N = p_t \left( 1 + \frac{\partial p_t}{\partial R_t} \frac{R_t}{p_t} \right) = p_t \left( 1 + \frac{1}{\epsilon_{R_t, p_t}} \right)$$

where the price elasticity of demand  $\epsilon_{R_t, p_t}$  is (negatively) defined for the CES-technology from (3)<sup>7</sup>

$$\epsilon_{R_t, p_t} = \frac{1}{F_{tRR} \frac{R_t}{F_{tR}}} = - \frac{\sigma}{1 - \theta_{tR}} < 0 \quad (27)$$

In general, the change in the price elasticity of resource demand which is directly induced by resource supply for a fixed capital stock depends on the elasticity of substitution

$$\left. \frac{\partial \epsilon_{R_t, p_t}}{\partial R_t} \right|_{K_t} = \frac{\sigma - 1}{\sigma} \frac{F_{tR}}{F_t} \epsilon_{R_t, p_t} \begin{matrix} \geq 0 \\ \leq 0 \end{matrix} \quad \text{for } \sigma \begin{matrix} \leq 1 \\ \geq 1 \end{matrix} \quad (28)$$

To assess the influence of market power on the extraction path, we evaluate the monopolistic Hotelling rule (25) for the optimal competitive extraction path  $(R_1^{C*}, R_2^{C*})$ . Since the Hotelling rule (26) for the competitive outcome holds per assumption, we have

$$\frac{1 + \frac{1}{\epsilon_{R_2, p_2}}}{1 + \frac{1}{\epsilon_{R_1, p_1}}} \begin{matrix} \geq 1 \\ < 1 \end{matrix} \quad \text{or} \quad \epsilon_{R_2, p_2} \begin{matrix} \leq \\ > \end{matrix} \epsilon_{R_1, p_1} \quad (29)$$

so that any inequality in (25) derives from the induced change in the price elasticity of demand between both periods.<sup>8</sup> Since the optimal competitive extraction path

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<sup>7</sup>The price elasticity of demand is always negative because the share of production factor  $f$ 's remuneration in total output  $\theta_{tf} = \frac{F_{tR} R_t}{F_t}$  cannot exceed unity by definition.

<sup>8</sup>Note that the price elasticity of demand is negatively defined according to (27).

$(R_1^{C*}, R_2^{C*})$  decreases for constant capital stocks we can conclude from (28) that

$$\epsilon_{R_2, p_2} \begin{matrix} \leq \\ \geq \end{matrix} \epsilon_{R_1, p_1} \quad \text{for} \quad \sigma \begin{matrix} \leq \\ \geq \end{matrix} 1$$

For  $\sigma = 1$ , i.e. for the special case of a Cobb-Douglas production technology, resource demand is iso-elastic. In this case, the marginal resource market revenue is directly proportional to the market prices so that the monopolistic and the competitive extraction paths clearly coincide completely (Stiglitz (1976)). If the absolute value of the price elasticity of demand falls in  $R$  or  $\sigma < 1$ ,<sup>9</sup> (23) implies that the monopolist – starting from the competitive extraction path – has an incentive to shift resources to the second period to meet condition (25) and thereby to slow down extraction. This result motivates the famous suggestion of the monopolist being “the conservationist’s best friend” (Solow (1974), referring to Hotelling (1931)). In contrast, if the absolute value of the price elasticity of demand increases in  $R$  for  $\sigma > 1$ ,<sup>10</sup> the monopolistic equilibrium is characterized by an even stronger decreasing supply path compared to the competitive case.

### 3.2.2 The Role of Capital Accumulation

We want to focus on positive capital accumulation over time, so that in the following  $K_2 > K_1$  holds. Due to the complementarity of fossil resources and capital, the resource will be more valuable with a higher capital stock so that there is an upward shift in the (inverse) resource demand. Regarding resource extraction under competition, at least part of the resource market price increase from period 1 to period 2, which is necessary for the competitive Hotelling condition (26) to hold, results from the upward shift of resource demand. Compared to the standard case with a fixed demand curve (i.e. fixed capital stocks) over time, positive capital accumulation therefore tends to raise future resource extraction. If capital accumulation is sufficiently high, this extraction shift might even lead to an increasing competitive supply path over time. This holds also true for the naive monopolist as marginal revenue increases with capital ((24)).

Note that an increase in the second period capital stock will also lead to a lower equilibrium interest rate  $i_2$  ceteris paribus, i.e. given the initially optimal competitive supply path for constant capital stocks, again due to the concavity of the CES production technology. This decrease in the interest rate additionally strengthens the incentives

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<sup>9</sup>i.e. as the price elasticity is negatively defined here, if  $\left. \frac{\partial \epsilon_{R_t, p_t}}{\partial R_t} \right|_{K_t} > 0$  and therefore  $\sigma < 1$ .

<sup>10</sup>i.e. if  $\left. \frac{\partial \epsilon_{R_t, p_t}}{\partial R_t} \right|_{K_t} < 0$  and therefore  $\sigma > 1$ .

for competitive resource suppliers to postpone extraction (cf. van der Meijden et al. (2014)). In the general equilibrium framework, any shift of resources to the second period will also influence capital accumulation itself according to 3 and the equilibrium interest rate according to (18). However, even though these feedback effects dampen the impact of capital accumulation on the equilibrium extraction path, they cannot reverse the qualitative result that competitive and monopolistic extraction will be slowed down compared to a setting with constant capital stocks.

Nevertheless, given that both the monopolist and the competitive market tend to increase second period resource supply, we cannot exclude that capital accumulation may reverse the mentioned conclusions about the comparison between the naive monopolist and the competitive market outcome. We know from the previous section that given (23) the monopolistic extraction bias is directly linked to the development of the price elasticity of demand over time for any given competitive extraction path (cf. (29)). With capital accumulation the price elasticity of demand changes due to the modified competitive extraction path, which we take as reference to characterize the monopolistic extraction bias, but also due to the influence of the higher capital stock. We summarize our results on the comparison between the naive monopolist and the competitive outcome with capital accumulation in the following proposition 1.

**Proposition 1.** *With capital accumulation, naive monopoly power still leads to an extraction shift to the future compared to the competitive equilibrium ("conservationist's best friend") if  $R_1^{C*} > R_2^{C*}$  and  $\sigma < 1$ . However, if capital accumulation leads to  $R_1^{C*} < R_2^{C*}$ , the monopolistic bias is ambiguous. A similar ambiguity arises for negative capital accumulation  $K_1 > K_2$ .*

The effect of capital accumulation on the price elasticity of demand is given by

$$\left. \frac{\partial \epsilon_{R_t, p_t}}{\partial K_t} \right|_{R_t} = (\sigma - 1) \frac{\theta_{tR} \frac{F_{tK}}{F_t}}{(1 - \theta_{tR})^2} \lesseqgtr 0 \quad \text{for } \sigma \lesseqgtr 1. \quad (30)$$

and crucially depends on the elasticity of substitution  $\sigma$ . The overall positive influence of capital accumulation on marginal revenue  $MR_t^N$  according to (24) therefore derives from two distinct, and sometimes counteracting, effects as rearranging shows

$$\left. \frac{\partial MR_t^N}{\partial K_t} \right|_{R_t} = F_{tRK} \left( 1 + \frac{1}{\epsilon_{R_t, p_t}} \right) - \frac{F_{tR}}{\epsilon_{R_t, p_t}^2} \left. \frac{\partial \epsilon_{R_t, p_t}}{\partial K_t} \right|_{R_t} > 0 \quad (31)$$

The first term on the right captures the induced upward shift in (inverse) resource de-

mand in  $R_t$ - $p_t$ -space that also drives the postponement of the extraction in the competitive case. For  $\sigma < 1$ , i.e. if capital and the resource are complementary in production, the second term on the right adds positively to the first. For  $\sigma > 1$ , the second term contributes negatively to the overall positive effect of capital accumulation on  $MR_t^N$  from (24).<sup>11</sup>

From comparing (28) and (30) we can conclude that the effect of capital accumulation on the (negatively defined) price elasticity of resource demand is exactly contrary to the effect of resource supply for any given elasticity of substitution  $\sigma \neq 1$ . If we have  $K_1 < K_2$  and  $R_1^{C*} > R_2^{C*}$  in the competition case, then both, the capital accumulation and the falling resource extraction, contribute to an unambiguous decrease (rise) in  $\epsilon_{R_t, p_t}$ <sup>12</sup> over time for  $\sigma < 1$  (for  $\sigma > 1$ ). This implies that the naive monopolist will choose a more (less) conservationist extraction path compared to the competitive market for  $\sigma < 1$  (for  $\sigma > 1$ ).<sup>13</sup> If either  $K_1 < K_2$  while  $R_1^{C*} < R_2^{C*}$  or  $K_1 > K_2$  while  $R_1^{C*} > R_2^{C*}$ , then the effects of capital dynamics and supply pattern on the price elasticity of demand  $\epsilon_{R_t, p_t}$  are counteracting each other. This implies that the incentive for the monopolist to deviate from the competitive outcome is ambiguous.<sup>14</sup>

For  $\sigma = 1$  and Cobb-Douglas technology the price elasticity of demand is not affected by changes in the capital stock and naive monopolistic and competitive extraction coincide with and without capital dynamics.

### 3.2.3 General Equilibrium Feedbacks

The role of capital accumulation was so far discussed with exogenous changes in the capital stock. In our model framework, however, the second period capital stock  $K_2$  and the future interest rate  $i_2$  are endogenous and lead to additional general equilibrium feedback effects while the monopolist deviates from the competitive extraction path. The interest rate even changes in the case with exogenously and constant capital stocks when switching from the competitive market to the naive monopoly in section 3.2.1. These feedback effects from the endogeneity of the capital market equilibrium have an impact on the naive monopolist's extraction path in equilibrium, even though the

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<sup>11</sup>Note, that for  $\sigma > 1$  resources and capital are substitutes in production. Capital accumulation then makes final goods producers less dependent on the resource and thereby lowers the market power the monopolist can exert in the second period.

<sup>12</sup>A decrease in the negative  $\epsilon$  means a rise in its absolute value.

<sup>13</sup>Nevertheless, we generally cannot conclude that the conservationist bias is stronger or weaker than in the partial equilibrium setting.

<sup>14</sup>Note that a scenario  $K_1 > K_2$  and  $R_1^{C*} < R_2^{C*}$  is logically inconsistent.

naive monopolist is not aware of them. For example, when the naive monopolist shifts resources to the future compared to the competitive outcome and thereby reproduces the conservationist bias the postponement of extraction goes along with an increase in  $i_2$  according to (18) and a decrease in  $K_2$  as

$$\frac{dK_2}{dR_2} < 0 \quad (32)$$

is assumed to hold throughout.

These feedback effects imply that in contrast to a partial equilibrium analysis, the left side of the Hotelling condition (21) effectively reacts to a shift of resources extraction from the first to the second period according to

$$\frac{d(1+i_2)MR_1^N}{dR_2} = \frac{d(1+i_2)MR_1^N}{dR_1} \frac{dR_1}{dR_2} = MR_1^N \frac{di_2}{dR_2} - \frac{\partial MR_1^N}{\partial R_1} \Big|_{K_1} > 0 \quad (33)$$

The effective total reaction of the right side of Hotelling condition (21) is given by

$$\frac{dMR_2^N}{dR_2} = \frac{\partial MR_2^N}{\partial R_2} \Big|_{K_2} + \frac{\partial MR_2^N}{\partial K_2} \Big|_{R_2} \frac{dK_2}{dR_2} = \frac{2-\sigma}{\sigma} \left( \theta_{2R} - \frac{1-\sigma}{2-\sigma} \right) \frac{dp_2}{dR_2} < 0 \quad (34)$$

which is unambiguously negative at least for  $MR_2^N \geq 0$  according to (23), (24) and  $\frac{dK_2}{dR_2} < 0$ .<sup>15</sup>

Since  $MR_1^N \frac{di_2}{dR_2} \geq 0$  and  $\frac{\partial MR_2^N}{\partial K_2} \Big|_{R_2} \frac{dK_2}{dR_2} < 0$ , these feedback effects strengthen the partial equilibrium reaction of the marginal revenue in each period and thus dampen the reallocation of resources by the naive monopolist when starting from the competitive market equilibrium relative to a partial equilibrium analysis.

### 3.3 Scenario NA: A 'Naive' Monopolist with a Capital Asset Motive

For the second scenario, we enlarge the monopolist's scope of information of the more widespread effects of resource supply. The monopolist is aware of the final goods' production technology in country  $I$  or, more specifically, of the complementarity of fossil resources and capital in production. However, the monopolist still evaluates feasible resource supply paths based on partial equilibrium considerations and therefore is still

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<sup>15</sup>Note that  $MR_t^N \geq 0$  implies  $\theta_{tR} \geq \frac{1}{2-\sigma}$ .



considered “naive” with respect to the general equilibrium feedback effects from the endogeneity of the capital market equilibrium overall.

Without all the general equilibrium related terms in (19), the equilibrium and the corresponding optimal resource extraction path then is characterized by the modified Hotelling condition

$$(1 + i_2^{NA*}) MR_1^{NA*} = MR_2^{NA*} \quad (35)$$

where we define the modified marginal revenue

$$MR_t^{NA} = MR_t^{NA}(K_t, R_t) = MR_t^N + F_{tKR}(K_t, R_t) s_{(t-1)E}(y_{1E}, \pi_{2E}, i_2) \quad (36)$$

as the marginal value of the resource from the monopolist’s perspective. We denote the optimal extraction policy by  $(R_1^{NA*}, R_2^{NA*})$  and, correspondingly, the equilibrium outcomes of all the endogenous variables by the superscript “ $NA^*$ ”.

From the benevolent sheikh’s perspective, there is now a positive and simultaneous influence of resource supply on the capital return on households’ savings running via the complementarity of resources and capital in final goods’ production.<sup>16</sup> This introduces an “asset motive” to the optimal resource supply decision, additional to the standard monopolistic strategic motive. The asset motive adds to the standard resource market revenue  $MR_t^N$  from (22) whenever country E’s households have positive foreign capital holdings  $s_{(t-1)E} > 0$ , i.e. no debt positions (cf. Calvo and Findlay (1978)). It is interesting that there may be situations where the naive monopolist considers the resource only as scarce if he accounts for the asset motive (i.e.  $MR_t^{NA} > 0$  while  $MR_t^N < 0$ ). With a finite time horizon, the scarcity of the resource from the monopolistic supplier’s perspective therefore not only depends on the resource stock available but also on the level of information that the supplier has.

An intuitive interpretation of the scenario at hand is again the notion of a benevolent sheikh. For a monopolistic profit maximizing oil firm there obviously would not be any reason to consider the returns on the households’ capital savings. Moreover, due to the asset motive pure resource profit maximization does no longer lead to households’ income or utility maximization. With households endogenously and optimally choosing

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<sup>16</sup>Since the sheikh still takes capital stocks as given, but is aware of the complementarity of resources and capital in final goods production, the resource price  $p_t$  and the capital price  $i_t$  are just functions of resource supply from his perspective with

$$\frac{\partial p_t}{\partial R_t} = F_{tRR}(K_t, R_t) \quad \text{and} \quad \frac{\partial i_t}{\partial R_t} = F_{tKR}(K_t, R_t)$$

savings, utility maximization by planning resource extraction is, in the end, equivalent to maximizing households' life-time income. However, as soon as the sheikh accounts for the asset motive, maximizing just resource income by choice of the resource extraction path generally cannot be optimal in contrast to scenario  $N$ .

### 3.3.1 Effects of the Asset Motive

We now consider the effect of the asset motive on the optimal extraction choice of the benevolent sheikh. For a single period, the asset motive always raises the marginal value of the resource from the monopolist's perspective and thereby in principle creates an incentive to increase resource supply *ceteris paribus* whenever there are positive capital holdings  $s_{(t-1)E} > 0$ . Along the lines of section 3.2, we can rearrange the extended marginal revenue of resource supply to<sup>17</sup>

$$MR_t^{NA} = \frac{p_t}{\sigma} \left[ \theta_{tR} + \theta_{tK} \frac{s_{(t-1)E}}{K_t} - (1 - \sigma) \right] \quad (37)$$

where  $\theta_{tf} = \frac{F_f(t)f_t}{F_t}$  again denotes factor  $f$ 's income share in total final goods output of period  $t$ . Thus, the weight of the asset motive relative to the standard monopoly considerations from scenario  $N$  in one period is determined by the share of total production (or income) that the monopolist's country  $E$  receives as capital income from abroad  $\theta_{tK} \frac{s_{(t-1)E}}{K_t}$ . The latter notably does not depend on the amount (value in terms of final goods) of capital assets held by country  $E$  but on the share of these assets in total capital stock.

However, for positive capital endowment and savings, there is an asset motive in both periods. Since we generally cannot solve for the optimal extraction path explicitly, we assess the effect of pursuing the asset motive on the extraction path by use of a thought experiment. We assume that the sheikh extracts according to the standard monopoly Hotelling rule (21) but then, for whatever reason, becomes aware of the (partial) complementarity of fossil resources and capital. The sheikh will update his decision rule for resource supply to (35) and assess the initially optimal extraction path  $(R_1^{N*}, R_2^{N*})$  based on this updated optimality condition. In the following, we aim to characterize the direction of the adjustment in resource extraction that will be necessary to fulfill the new equilibrium condition (35).

As a benchmark, we derive the case when the asset motive is neutral relative to the

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<sup>17</sup>A similar transformation can be found in Calvo and Findlay (1978).

standard monopoly outcome so that it does not induce any change in resource supply. Correspondingly, taking extraction path  $(R_1^{N*}, R_2^{N*})$  from the naive monopolist's equilibrium as reference supply policy, neutrality of the asset motive implies that

$$\frac{MR_2^{NA}(K_2^{N*}, R_2^{N*})}{MR_1^{NA}(K_1, R_1^{N*})} = 1 + i_2^{N*} = \frac{MR_2^N(K_2^{N*}, R_2^{N*})}{MR_1^N(K_1, R_1^{N*})}$$

holds when we combine the equilibrium resource supply conditions (21) and (35). Rearranging and using  $\frac{\partial i_2}{\partial R_2} = F_{2KR}$ , yields

$$\frac{F_{2KR}(K_2^{N*}, R_2^{N*}) \cdot s_{1E}(y_{1E}^{N*}, \pi_{2E}^{N*}, i_2^{N*})}{F_{1KR}(K_1, R_1^{N*}) \cdot s_{0E}} = \frac{MR_2^{N*}}{MR_1^{N*}} = 1 + i_2^{N*} \quad (38)$$

Thus, the asset motive is exactly neutral if the returns for conserving one resource unit underground are the same in terms of capital income and resource income.<sup>18</sup>

We summarize our results on the effect of the asset motive in the following proposition.

**Proposition 2.** *The effect of the asset motive on the monopolist's extraction decision in comparison to the equilibrium outcome of scenario N  $(R_1^{N*}, R_2^{N*})$  depends on country E's asset accumulation. The asset motive is exactly neutral if*

$$\frac{s_{1E}^{N*}}{s_{0E}} = \frac{\frac{MR_2^{N*}}{F_{2KR}(K_2^{N*}, R_2^{N*})}}{\frac{MR_1^{N*}}{F_{1KR}(K_1, R_1^{N*})}} \equiv \Phi(R_1^{N*}, R_2^{N*}) \quad (39)$$

If  $\frac{s_{1E}}{s_{0E}} < \Phi$ , the asset motive leads to a shift of resources to the first period. In contrast, for  $\frac{s_{1E}}{s_{0E}} > \Phi$  or  $s_{0E} = 0$  and  $s_{1E} > 0$  the asset motive induces a postponement of extraction.

Taking the extraction path  $(R_1^{N*}, R_2^{N*})$  as reference effectively fixes all the endogenous variables from the conditional market equilibrium but country E's capital savings  $s_{1E}$ .

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<sup>18</sup> In this case the difference in the second and the first period share of total production which is captured by country E and taken into account by the sheikh when choosing resource supply is the same as when the sheikh does not pursue the asset motive and just considers resource income as in scenario N, i.e. we have

$$\theta_{2R}^{N*} + \theta_{2K}^{N*} \frac{s_{1E}}{K_2^{N*}} - \left( \theta_{1R}^{N*} + \theta_{1K}^{N*} \frac{s_{0E}}{K_1} \right) = \theta_{2R}^{N*} - \theta_{1R}^{N*}$$

When shifting resources to period  $t$ , the sheikh knows that he can capture from the marginal production increase  $F_{tR}$  the share  $\theta_{tR} + \theta_{tK} \frac{s_{(t-1)E}}{K_t}$  if he pursues the asset motive. In contrast, from the purely naive monopolist's perspective this share is reduced to  $\theta_{tR}$ .

Since the aggregated capital stock  $K_2$  is a function of the resource supply path only.<sup>19</sup> the reference equilibrium from scenario  $N$  does not depend on the distribution of capital endowment between both countries. In contrast, the savings decision of households in country  $E$  is a function of the overall first period household income  $y_{1E}$ .<sup>20</sup> Therefore, not only  $MR_1^{NA}$  but also capital holdings of households in the second period  $s_{1E}$  directly depend on the (exogenous) distribution of the given capital stock  $K_1$  between both countries. To isolate the role of capital endowment  $s_{0E}$ , we solve neutrality condition (38) for the ratio of asset holdings which gives the threshold  $\Phi$  in (39). The threshold  $\Phi$  may be lower or greater than unity, in general.<sup>21</sup> For  $\sigma = 1$ , the factor shares  $\theta_{tf}$  for  $f = K_t, R_t$  are constant over time<sup>22</sup> so that  $\Phi = \frac{K_2^{N*}}{K_1}$ .<sup>23</sup>

If  $\frac{s_{1E}}{s_{0E}} > \Phi$ , we can refer to (38) and conclude that conserving a marginal resource unit for future supply yields a higher return from capital income than from resource income due to the increase in capital holdings. This implies that the sheikh is confronted with the inequality

$$MR_2^{NA}(K_2^{N*}, R_2^{N*}) > (1 + i_2^{N*})MR_1^{NA}(K_1, R_1^{N*})$$

when he suddenly becomes aware of the asset motive and evaluates the modified Hotelling rule with assets (35) for the extraction path  $(R_1^{N*}, R_2^{N*})$  which is optimal according to (25). For  $\frac{s_{1E}}{s_{0E}} < \Phi$ , the contrary holds true.

In either case, the sheikh has an incentive to adjust his extraction path and will shift resources to the period where the marginal resource value from his perspective is higher. For  $\frac{s_{1E}}{s_{0E}} > \Phi$ , the asset motive leads to a postponement of extraction compared to the standard monopoly equilibrium of scenario  $N$ . This is also the case for  $s_{0E} = 0$  when the asset motive only adds to the second period marginal resource value.<sup>24</sup> In contrast, for  $\frac{s_{1E}}{s_{0E}} < \Phi$ , the asset motive induces the sheikh to accelerate extraction compared to the standard monopoly equilibrium, because the positive effect of resource supply

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<sup>19</sup>Recall that this is due to our assumption of symmetric homothetic preferences in both countries and the exogeneity of the aggregated capital endowment  $K_1$ .

<sup>20</sup>Note that  $y_{1E} = \pi_{1E} + (1 + i_1)s_{0E}$ .

<sup>21</sup>Recall that  $\theta_{tR} > 1 - \sigma$  for  $MR_t^N > 0$ .

<sup>22</sup>For  $\sigma = 1$  or  $\alpha = 0$ , the CES-technology in (3) is equivalent to a Cobb-Douglas production function  $F_t = K_t^\gamma R_t^\lambda L^{1-\gamma-\lambda}$  so that the income share of the respective production factor is given by the respective constant exponent.

<sup>23</sup>By use of (22), we may rewrite  $\Phi = \frac{K_2^{N*}}{K_1} \frac{\frac{\theta_{2R}^{N*} - (1-\sigma)}{\theta_{1R}^{N*} - (1-\sigma)}}{\frac{\theta_{2K}^{N*}}{\theta_{1K}^{N*}}}$ .

<sup>24</sup>Note that the elasticity of substitution determines whether and how neutrality condition (39) is violated for a given capital endowment  $s_{0E}$  as it influences the right side and via the savings decision also the left side. We discuss the role of the elasticity of substitution in more detail in section 5.

on capital income in the first period dominates the capital income effect in the second period.

The impact of a redistribution of capital endowments is summarized in proposition 3.

**Proposition 3.** *A redistribution of capital endowments towards country  $E$  always leads to an acceleration of extraction.*

A redistribution of capital endowments between both countries does not influence the threshold  $\Phi$  because the equilibrium outcome in scenario  $N$  does not depend on the distribution of capital endowments. The marginal savings propensities then are insensitive to changes in the capital endowment distribution, too. We show in appendix B.1.1 that savings  $s_{1E}$  therefore are ceteris paribus linearly increasing in capital endowment  $s_{0E}$  when capital endowments are redistributed to country  $E$  whereas we have<sup>25</sup>

$$\left. \frac{\partial \frac{s_{1E}}{s_{0E}}}{\partial s_{0E}} \right|_{K_1, R_1^{N*}, R_2^{N*}} = \frac{1}{s_{0E}} \left[ \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) - \frac{s_{1E}}{s_{0E}} \right] = -\frac{s_{1E}(0)}{s_{0E}^2} < 0 \quad (40)$$

so that the ratio of asset holding will fall with any redistribution of capital endowment to country  $E$ . This implies that the monopolist's incentive to postpone extraction is more and more reduced and is even reversed if the ratio of second to first period capital holdings falls below  $\Phi$ . By increasing first period capital holdings, the redistribution of endowments disproportionally strengthens the capital income component in the first period over the one of the second period and thereby lowers the return via capital income which the sheikh can get from conserving resources underground.

The capital endowment redistribution to country  $E$  is, however, limited by the given first period capital stock  $K_1$  so that there is a lower bound on the ratio of asset holdings. Therefore, the neutrality condition (39) cannot be met even for any  $s_{0E} > 0$  (cf. appendix B.1.1) if

$$\Phi \leq \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) = \lim_{s_{0E} \rightarrow \infty} \left. \frac{s_{1E}}{s_{0E}} \right|_{K_1, R_1^{N*}, R_2^{N*}}$$

where  $\frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*})$  measures the marginal increase in savings from a marginal increase in capital endowment upon redistribution. In this case, we always have  $\frac{s_{1E}}{s_{0E}} > \Phi$  and a postponement of extraction compared to the outcome of scenario  $N$  for all  $s_{0E} > 0$ .

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<sup>25</sup>  $s_{1E}(0)$  denotes savings for the case of no capital endowment  $s_{0E} = 0$ .

### 3.3.2 Asset Motive and Competitive Resource Extraction

We showed that the asset motive may induce the monopolist both to speed up or to slow down extraction depending on the capital endowment  $s_{0E}$ . In general, the asset motive, therefore, may strengthen, dampen or even reverse the conservationist bias in the extraction pattern which is introduced by market power in comparison with a competitive resource sector for  $\sigma < 1$  (see section 3.2.1).

To analyze the extraction decision of the naive monopolist pursuing the asset motive in comparison with the competitive outcome we again rely on a comparative static analysis. We assume that the optimal competitive extraction path  $(R_1^{C*}, R_2^{C*})$  falls over time even though we have capital accumulation and evaluate Hotelling condition (35) for the optimal competitive extraction. The asset motive will exactly overturn the conservationist bias of the naive monopolist without asset motive in scenario  $N$  if

$$(1 + i_2^{C*})MR_1^{NA}(K_1, R_1^{C*}) = MR_2^{NA}(K_2^{C*}, R_2^{C*}) \quad (41)$$

The following proposition summarizes our results.

**Proposition 4.** *The asset motive counterbalances the conservationist bias from (naive) monopoly power for  $\sigma < 1$  and a decreasing competitive supply path if*

$$\Delta \equiv \theta_{2R} + \theta_{2K} \frac{s_{1E}}{K_2} - \left( \theta_{1R} + \theta_{1K} \frac{s_{0E}}{K_1} \right) = 0 \quad \text{for } (R_1^{C*}, R_2^{C*}). \quad (42)$$

If  $\Delta < 0$ , the asset motive reverses the conservationist bias whereas for  $\Delta > 0$ , the naive monopolist with asset motive still extracts more conservationist than the competitive market. For iso-elastic demand, the equivalency of competitive and monopolistic extraction may fall apart. A reversal of the conservationist bias is more likely with higher asset endowments in country  $E$ .

Since along the optimal competitive extraction path the Hotelling rule (26) holds, we can rearrange and simplify the equality condition (41) using (37) to get (42). The parameter  $\Delta$  indicates whether the share of final goods' production which the sheik consciously can capture as factor remuneration for his constituency increases or falls over time for the competitive equilibrium extraction path.<sup>26</sup>

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<sup>26</sup> The reasoning is, therefore, similar to the previous assessment of the effect of the asset motive in comparison with the purely naive monopolist from scenario  $N$ . However, whereas the latter only accounts for resource income and thereby considers the development of the resource income share over time when choosing the extraction path, a competitive resource supplier does not account for his

The monopolist will shift resources to the period where the share of the marginal increase in total output which he captures as factor income is greater. Therefore, if  $\Delta < 0$  for  $(R_1^{C*}, R_2^{C*})$ , the monopolist has an incentive to shift resources to the first period and thereby to reverse the conservationist bias. In contrast, if  $\Delta > 0$ , the monopolist will choose a more conservationist extraction policy relative to the competitive extraction path. In this case, the conservationist bias may be dampened or strengthened, in general.<sup>27</sup>

Even though iso-elastic resource demand for  $\sigma = 1$  implies constant resource and capital factor shares  $\theta_{tR}$  and  $\theta_{tK}$  (see above), resource market power no longer needs to be neutral compared to the competitive outcome when the monopolist pursues the asset motive. The reason is that at least the share of country  $E$ 's assets in the capital stock is very likely to change over time. Moreover, since the naive monopoly outcome coincides with the competitive case for  $\sigma = 1$ , the effect of the asset motive on the supply choice of the monopolist can equivalently be identified from  $\Delta$  from (42) and the threshold  $\Phi$  from (39).

With a redistribution of endowment to country  $E$ ,  $\Delta$  falls as the ratio of asset holdings  $\frac{s_{1E}}{s_{0E}}$  decreases (cf. (51)) whereas competitive extraction and thereby the factor shares  $\theta_{tR}, \theta_{tK}$  do not change due to the assumption of symmetric homothetic consumption preferences. Thus, the asset motive therefore is more likely to reverse the conservationist bias the higher the asset endowment of country  $E$ . This is also in line with our previous conclusion that an increase in asset endowment  $s_{0E}$  generally creates an incentive to speed up extraction relative to the standard monopoly case.

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influence on aggregated supply, production and market prices at all.

Moreover, note that the conservationist bias for  $\sigma < 1$  and a falling competitive extraction path ( $R_1^{C*} > R_2^{C*}$ ) (see section 3.2) arises because we then have  $\theta_{1R} < \theta_{2R}$ . Similarly, the monopolist speeds up extraction for  $\sigma > 1$  when  $\theta_{1R} > \theta_{2R}$ , and does not deviate from the competitive extraction path for  $\sigma = 1$  which implies  $\theta_{1R} = \theta_{2R}$ .

Therefore, with and without asset motive, the extraction decision of the monopolist in comparison to the competitive market is directly linked to the development of the share of total production which the monopolist can capture for “his” households and which the monopolist, depending on his level of information, is consciously influencing by his extraction decision.

<sup>27</sup>Note that for  $\Delta < 0$  we must have  $\theta_{1K} \frac{s_{0E}}{K_1} > \theta_{2K} \frac{s_{1E}}{K_2}$  as the conservationist bias in the standard naive monopoly case follows from  $|\epsilon_{R_1, p_1}| < |\epsilon_{R_2, p_2}|$  which implies  $\theta_{1R} < \theta_{2R}$  by (27). In contrast, for  $\Delta > 0$  the capital income share of country  $E$  may rise or fall over time.

### 3.4 Scenario G: General Equilibrium Information without Asset Motive

We now assume that the monopolist realizes the endogeneity of second period resource demand  $p_2(K_2, R_2)$  in general equilibrium, but does not consider his influence on the return on capital. The monopolist therefore accounts for the total price reaction  $\frac{dp_2}{dR_2}$  from (17), which notably also includes the feedback from capital accumulation. At the same time, however, he does not recognize (or does not care for<sup>28</sup>) any influence on the interest rate, neither from the complementarity effect of resource supply ( $F_{tKR}$ ) nor from the induced change in capital accumulation ( $F_{2KK} \frac{dK_2}{dR_2}$ ).

By suppressing the asset related terms in (19), optimal extraction and the overall equilibrium in this third scenario  $G$  is therefore defined by condition

$$(1 + i_2^{G*})MR_1^{G*} = MR_2^{G*} \quad (43)$$

where the marginal resource value from the sheikh's perspective is given by

$$MR_2^G = MR_2^G(K_2, R_2) = p_2 + \frac{dp_2}{dR_2}R_2 = MR_2^N + \frac{\partial p_2}{\partial K_2}R_2 \frac{dK_2}{dR_2} \quad (44)$$

The optimal extraction path, which is again implicitly defined by (43), is denoted by  $(R_1^{G*}, R_2^{G*})$  and correspondingly the equilibrium outcome of the endogenous variables by the superscript “ $G^*$ ”. We may interpret scenario  $G$  as the general equilibrium counterpart to scenario  $N$  of a naive monopolist in section 3.2. With the scenario at hand we introduce a distinction between cases with and without an asset motive in general equilibrium, which is in line with the distinction of scenarios  $N$  and  $NA$  for the naive monopolist.

#### 3.4.1 Addiction Motive

To analyze the influence of the general equilibrium feedback effects we compare condition (43) with (25), the respective Hotelling rule from scenario  $N$ . Since the first period's marginal revenues formally coincide without pursuing any asset motive and with given capital endowments  $K_1$ , we can first restrict the analysis to the second period. In particular, we do not need to derive an intertemporal neutrality condition as

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<sup>28</sup>Maybe the intuitive interpretation as an oil ministry as more appropriate than a comprehensively benevolent sheikh in this scenario.



in scenario  $NA$  in section 3.3.

For the comparison of the optimal extraction paths, that are implicitly defined by (43) and (25), we again assume that the sheikh initially supplies the resource according to (25), but then notices the dependency of second period demand on his extraction policy via capital accumulation, so that he updates his supply policy to (43). Proposition 5 summarizes the results on the comparison with the naive monopolist's outcome.

**Proposition 5.** *Letting the monopolist become aware of the endogeneity of second-period resource demand, the so-called addiction motive of resource supply arises in general equilibrium if capital and resources are complementary in production and  $\frac{dK_2}{dR_2} < 0$ . The addiction motive always induces the monopolist to speed up extraction compared the naive monopolist's equilibrium solution from scenario  $N$ . The strength of the addiction motive depends on the relationship between first period resource supply and second period resource demand but not on the distribution of capital endowments.*

From (17) we know that

$$\frac{dp_2}{dR_2} < \frac{\partial p_2}{\partial R_2} < 0$$

for  $\frac{dK_2}{dR_2} < 0$ , and correspondingly

$$MR_2^G = p_2 + \frac{\partial p_2}{\partial R_2} + \frac{\partial p_2}{\partial K_2} \frac{dK_2}{dR_2} < MR_2^N = p_2 + \frac{\partial p_2}{\partial R_2}$$

for any extraction path  $(R_1, R_2)$ . This implies on the one hand that there is no point of intersection between  $MR_2^G$  and  $MR_2^N$  (for the same extraction path) as long as  $\frac{dK_2}{dR_2} \neq 0$ . Moreover, as before, the Hotelling rule (43) only constitutes an equilibrium condition if  $MR_1^N, MR_2^G > 0$  for extraction path  $(R_1^{G*}, R_2^{G*})$  and complete exhaustion of the resource stock  $\bar{R}$ . Changing the monopolist's level of knowledge from scenario  $N$  to scenario  $G$  thus could turn a scarce resource into an abundant one for some extraction paths from his perspective. Assuming, as we do, that the resource constraint indeed binds, we can also conclude from these observations that for the optimal extraction path in scenario  $G$   $(R_1^{G*}, R_2^{G*})$  the marginal revenue in scenario  $N$   $MR_2^N(R_1^{G*}, R_2^{G*})$  from (22) has to be strictly positive, too.

For extraction policy  $(R_1^{N*}, R_2^{N*})$ , which is initially optimal in our thought experiment, we therefore always have  $MR_2^G < MR_2^N$ . The first period marginal revenues and the interest rate  $i_2$  completely coincide for the given extraction path  $(R_1^{N*}, R_2^{N*})$ . Thus,

the sheikh will unambiguously speed up extraction as soon as he becomes aware of his negative influence on capital accumulation, future resource demand and the value of future extraction.

By shifting resources from the second to the first period, the monopolist aims to boost capital accumulation and to increase – given the complementarity of capital and resources in production – the dependency of the importing economy on the input factor “oil” or, equivalently, future resource demand. The monopolist therefore may be seen as an “oil-drug” dealer who is not only exploiting but even manipulating country  $I$ ’s addiction to fossil resources. We refer to this strategic component of resource supply in general equilibrium as “addiction motive” which inherently arises from the introduced general equilibrium framework for  $\frac{dK_2}{dR_2} < 0$  as soon as we let the monopolist become aware of the endogeneity of second period resource demand.

The effect of the addiction motive may also be described with the aid of a total general equilibrium price elasticity of demand, which incorporates the general equilibrium feedback effects. The according reformulation of the Hotelling condition shows that the higher the sensitivity of the capital stock  $\frac{dK_2}{dR_2} \frac{K_2}{R_2}$ , the less price elastic will be second period demand and the less attractive will be second period resource supply from the monopolist’s perspective. Moreover, with symmetric homothetic preferences the relationship between aggregated capital accumulation and the extraction path does not depend on the distribution of asset endowments between both countries. In contrast to the asset motive, any redistribution of endowments is completely neutral with respect to the addiction motive.

As in general equilibrium the interest rate reacts with shifting resources according to (18) and depending on the elasticity of substitution between resource and capital, the addiction motive is dampened and the difference between the equilibrium extraction paths defined by (43) and by (21) is reduced. The acceleration of extraction cannot be reversed though.

### 3.4.2 Addiction Motive and Competitive Extraction

Proposition 5 does not depend on the elasticity of substitution being lower or greater than unity. Extraction is always accelerated relative to the naive monopoly in scenario  $N$ . The occurrence of the addiction motive thus modifies the comparison monopoly vs. competition in section 3.2.1 as summarized by the following proposition.

**Proposition 6.** *The addiction motive induces the monopolist to additionally accelerate extraction. For  $\sigma > 1$ , the monopolist accelerates extraction even further compared to the competitive outcome than the naive monopolist. He also speeds up extraction for  $\sigma = 1$  (iso-elastic demand) so that the equivalency of monopolistic and competitive extraction no longer holds. For  $\sigma < 1$  and a sufficiently high  $\frac{dK_2}{dR_2}$ , the addiction motive may even reverse the conservationist bias of the standard naive monopoly case.*

The condition for a reversal of the conservationist bias is explained in the appendix (cf. B.2.2).

### 3.4.3 General Equilibrium Feedbacks

Due to the general equilibrium feedback effects, the total reaction of the future marginal revenue  $MR_2^G$  to changes in  $R_2$  is of ambiguous sign. All additive terms in  $\frac{dMR_2^G}{dR_2}$  are negative (cf. appendix B.2.1) apart from  $F_{2KR}R_2\frac{d^2K_2}{(dR_2)^2}$ , which can be positive, at least according to our numerical example in figure 3 (cf. appendix). Therefore, we can not exclude one or more areas with a positive slope and the incidence of multiple (interior) equilibria, although we did not observe any in our numerical examples. But even if multiple equilibria occurred,  $MR_2^G < MR_2^N$  holds and the conclusion that the addiction motive always leads to an acceleration of extraction remains unaffected.

## 3.5 Scenario GA: General Equilibrium Information with Asset Motive

Finally, if we let the sheikh be aware of the endogeneity of the second period capital stock as well as of the dependency of the capital income on resource supply, we return to equilibrium condition (19) and consider a truly omniscient and benevolent resource monopolist. In general equilibrium, a full level of awareness of the economic structure naturally leads the benevolent monopolist to pursue both strategic motives at the same time, the asset motive and the addiction motive. In the following, we first will show that the asset motive is modified by the general equilibrium feedback effect from the capital market. Moreover, we will discuss the interaction between both strategic motives which characterizes the supply policy in this final scenario by comparison with the naive standard monopoly case and with the competitive extraction path.

### 3.5.1 The Asset Motive in General Equilibrium and the Interrelationship Between the Resource and the Capital Market

We start by considering the modified marginal revenues  $MR_t^{GA}$  in (19) in more detail. The left side of (19) is identical to the left side in (35) so that we have

$$(1 + i_2)MR_1^{GA} = (1 + i_2)MR_1^{NA} \quad \text{for any extraction path } (R_1, R_2).$$

Expanding the monopolist's awareness does not change his marginal revenue in the first period in comparison to scenario  $NA$ , since the present capital stock  $K_1$  is fixed and does not cause any general equilibrium feedback effects.

Since the omniscient monopolist explicitly recognizes the endogeneity of the second period capital stock, the marginal revenues in the second period of scenarios  $NA$  and  $GA$  are not identical, i.e. the right side of (19) significantly differs from the right side in (35) as decomposing  $MR_2^{GA}$  by use of (17) and (18) demonstrates

$$MR_2^{GA} = p_2 + \left( \frac{\partial p_2}{\partial R_2} + \frac{\partial p_2}{\partial K_2} \frac{dK_2}{dR_2} \right) R_2 + \left( \frac{\partial i_2}{\partial R_2} + \frac{\partial i_2}{\partial K_2} \frac{dK_2}{dR_2} \right) s_{1E} \quad (45)$$

**Proposition 7.** *Letting the naive monopolist with a partial or naive asset motive become aware of the overall economic structure strengthens the asset motive in period 2 by adding a feedback effect from capital accumulation, which unambiguously contributes to an extraction shift to the future.*

With full general equilibrium knowledge, the monopolist pursuing the asset motive not only considers the positive influence of resource supply on capital returns from the complementarity of fossil resources and capital but also the effect of changes in capital accumulation that are induced by any shift in the extraction path. The asset motive in the “true” marginal revenue in period 2 (from the omniscient monopolist's point of view), therefore, encompasses an additional component relative to scenario  $NA$  which supports the complementarity effect on the capital return

$$\frac{di_2}{dR_2} s_{1E} = \frac{\partial i_2}{\partial R_2} s_{1E} + \frac{\partial i_2}{\partial K_2} \frac{dK_2}{dR_2} s_{1E}$$

according to (18). This feedback effect from capital accumulation is positive because we have a strictly concave production technology ( $F_{2KK} < 0$ ) and assume  $\sigma\eta > 1$  and therefore  $\frac{dK_2}{dR_2} < 0$  (see (32)) throughout the analysis. Shifting resources to the second period, on the one hand, increases future capital returns since additional resources foster

the productivity of the given capital stock. On the other hand, the future capital stock will be lower, which also raises the marginal productivity of capital, i.e. (in equilibrium) the interest rate  $i_2$ . Thus, the second period asset motive is generally strengthened by the additional term  $\frac{\partial i_2}{\partial K_2} \frac{dK_2}{dR_2} s_{1E}$  for given savings and capital endowment which in principle establishes an incentive for the omniscient monopolist to slow down extraction relative to scenario  $NA$ .

The decomposition of  $MR_2^{GA}$  in (45), however, also demonstrates that becoming aware of the overall economic structure and the interrelation between capital and resource market also introduces the addiction motive of scenario  $G$ . In total, therefore, two additional but counteracting considerations influence the monopolist's supply strategy. The addiction motive creates an unambiguous incentive to speed up extraction. Thereby, it obviously counteracts the strengthening of the second period's asset motive. The overall implication of being aware of the interrelation between the capital and resource markets for the monopolist's supply decision therefore depends on the weighting of these counteracting effects and motives. To this end, we may define

$$\Psi \equiv \frac{\partial p_2}{\partial K_2} R_2 + \frac{\partial i_2}{\partial K_2} s_{1E} \quad (46)$$

which is a nonlinear function of  $R_2$  and generally of ambiguous sign, discussed in more detail in appendix B.3.1. Wherever  $\Psi > 0$ , we have  $\frac{\partial p_2}{\partial K_2} R_2 > -\frac{\partial i_2}{\partial K_2} s_{1E}$  and the addiction motive dominates the strengthening of the second period's asset motive. In this case, internalizing the feedback effect from capital accumulation creates an incentive for the omniscient monopolist to accelerate extraction at the given extraction path for which we evaluate  $\Psi$ . In contrast, for  $\Psi < 0$ , the strengthening of second period's asset motive outweighs the addiction motive so that the feedback effect from capital accumulation overall works towards a more conservationist extraction policy relative to the given extraction path. By (20) and (36),  $\Psi$  also indicates whether the marginal resource value from the omniscient monopolist's perspective exceeds the marginal revenue from the perspective of the naive monopolist with asset motive or not.

### 3.5.2 Scenario GA vs. Scenario G

The general equilibrium counterpart to our analysis of the asset motive in section 3.3 is a comparison between the omniscient monopolist's outcome and scenario  $G$  from section 3.4. Proceeding along the lines of section 3.3 we characterize the effect of the full general equilibrium asset motive on the extraction path relative to a monopolist who

already pursues the addiction motive only. We summarize our results by the following proposition.

**Proposition 8.** *Taking the addiction scenario  $G$  as reference, the asset motive may induce the omniscient monopolist to both postpone or speed up extraction in general equilibrium. It is exactly neutral if*

$$\frac{s_{1E}}{s_{0E}} = \frac{MR_2^{G*} \frac{\partial i_1}{\partial R_1}}{MR_1^{G*} \frac{di_2}{dR_2}} \equiv \hat{\Phi} \quad (47)$$

*The monopolist accelerates extraction for  $\frac{s_{1E}}{s_{0E}} < \hat{\Phi}$  but slows down extraction for  $\frac{s_{1E}}{s_{0E}} > \hat{\Phi}$  (for  $\frac{dK_2}{dR_2} < 0$ ). A redistribution of capital endowments to country  $E$  makes the monopolist shift the resource extraction to the present.*

The overall asset motive in general equilibrium (i.e. including the partial complementarity effect  $F_{tKR}$  as well as the general equilibrium feedback via capital accumulation for the second period  $F_{2KK} \frac{dK_2}{dR_2}$ ) will be neutral compared to the pure addiction scenario  $G$  so that it does not induce any change in the optimal extraction path if

$$\frac{MR_2^{GA*}}{MR_1^{GA*}} = \frac{MR_2^{G*}}{MR_1^{G*}} = 1 + i_2^{G*}$$

holds for extraction path  $(R_1^{G*}, R_2^{G*})$  that is implicitly defined by (43). Following the reasoning from section 3.3.1, we isolate the effect of capital endowment  $s_{0E}$  by solving for the ratio of asset holdings which yields the modified neutrality threshold in (47). For extraction path  $(R_1^{G*}, R_2^{G*})$  we may additionally substitute for  $\frac{MR_2^{G*}}{MR_1^{G*}}$  from (43). The modified threshold  $\hat{\Phi}$  thus is the general equilibrium counterpart of threshold  $\Phi$  from (39). Since  $MR_1^G = MR_1^N$  and  $MR_2^G < MR_2^N$  according to (22), (44) and (17) as well as  $F_{2KR} < \frac{di_2}{dR_2}$  according to (18), we have  $\Phi > \hat{\Phi}$  for any extraction path.<sup>29</sup> Note, however, that we evaluate the neutrality conditions (39) and (47) for different reference extraction paths.

The interpretation of the modified neutrality condition (47) is completely analog to our previous discussion of threshold  $\Phi$  in section 3.3.1. If  $\frac{s_{1E}}{s_{0E}} < \hat{\Phi}$ , conserving resources underground yields a lower return in terms of capital income from the now omniscient monopolist's perspective than in terms of pure resource market income. Therefore,

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<sup>29</sup>From the definition of  $\hat{\Phi}$  and  $\Phi$  in (39) also follows that  $\hat{\Phi} = \Phi \frac{F_{2KR}}{\frac{di_2}{dR_2}} \frac{MR_2^G}{MR_2^N}$  which shows that  $\hat{\Phi} < \Phi$  as  $\frac{F_{2KR}}{\frac{di_2}{dR_2}} < 1$  and  $\frac{MR_2^G}{MR_2^N} < 1$ .

the monopolist will speed up extraction even further (compared to the already non-conservationist extraction path of the addiction scenario) as soon as he updates his extraction strategy from (43) to (19). As the general equilibrium component of the asset motive contributes to a postponement of extraction, this incentive to speed up extraction even more than in the addiction case  $G$  for  $\frac{s_{1E}}{s_{0E}} < \hat{\Phi}$  must be established by the naive or partial equilibrium component of the asset motive.<sup>30</sup>

For  $\frac{s_{1E}}{s_{0E}} > \hat{\Phi}$ , the second period asset motive overall gives the monopolist an incentive to conserve more resources for future supply compared to the reference extraction path  $(R_1^{G*}, R_2^{G*})$ . However, in this case, we cannot attribute the incentive to slow down extraction to a specific component of the second period's asset motive because the complementarity component of the asset motives may or may not establish an incentive to speed up extraction at the same time. This also demonstrates that we generally cannot conclude from the threshold condition (47) on the sign of the weighting parameter  $\Psi$  from (46).

Since the addiction motive and the according extraction decision in scenario  $G$  are completely independent of the distribution of capital endowments (symmetric homothetic preferences), taking extraction path  $(R_1^{G*}, R_2^{G*})$  as reference, therefore, fixes all the endogenous variables which are functions of the extraction path. The only exception is that for the omniscient monopolist savings  $s_{1E}$  depend on the initial distribution of capital endowments between both countries, as in section 3.3.1. Thus,  $\hat{\Phi}$ , just as  $\Phi$ , is independent of the distribution of capital endowments whereas we know (cf. (51) in the appendix) that the ratio of asset holdings is a decreasing function of capital endowments for a given extraction path. Just as for the naive monopolist with asset motive, we therefore can conclude the following:

**Proposition 9.** *A redistribution of the capital endowment to country  $E$  ceteris paribus will accelerate extraction in absolute terms (and thus also relative to the addiction scenario which remains unaffected by the endowment redistribution) by strengthening the capital income motive of resource supply in the first period relative to the one in the second period.*

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<sup>30</sup>I.e. we must have  $\frac{s_{1E}}{s_{0E}} < \hat{\Phi} < \Phi$ .

### 3.5.3 Omniscient vs. Purely Naive Monopoly

As in sections 3.3 and 3.4 the natural benchmark for the omniscient monopolist's extraction decision (defined by (19)) is the naive monopoly scenario  $N$ . In the following, we characterize the additional extraction incentives of the omniscient monopolist and their implications for the optimal extraction path by investigating the incentive of the omniscient monopolist to deviate from reference path  $(R_1^{N*}, R_2^{N*})$  which fulfills the naive monopolist's Hotelling rule (25). We summarize our results in the next proposition.

**Proposition 10.** *The omniscient monopolist exactly follows the extraction policy of the naive monopolist if*

$$\frac{s_{1E} + \frac{\Psi}{F_{2KR}} \frac{dK_2}{dR_2}}{s_{0E}} = \Phi \quad \text{for extraction path } (R_1^{N*}, R_2^{N*}). \quad (48)$$

*If  $\frac{s_{1E} + \frac{\Psi}{F_{2KR}} \frac{dK_2}{dR_2}}{s_{0E}} > \Phi$ , the omniscient monopolist chooses a more conservationist extraction path and for  $\frac{s_{1E} + \frac{\Psi}{F_{2KR}} \frac{dK_2}{dR_2}}{s_{0E}} < \Phi$  a less conservationist extraction path than the naive monopolist.*

Since full general equilibrium information affects both, the first period and the second period marginal resource value from the monopolist's perspective, we start by analyzing analogue to section 3.3 when the additional information is completely neutral relative to the standard naive monopoly case. In this sense, neutrality implies that by combining Hotelling conditions (25) and (19)

$$\frac{MR_2^{GA*}}{MR_1^{GA*}} = \frac{MR_2^{N*}}{MR_1^{N*}} = 1 + i_2^{N*}$$

holds for extraction path  $(R_1^{N*}, R_2^{N*})$ . Using (20), (22) and (46) we can rearrange this neutrality condition along the lines of (39) to get (48). The threshold  $\Phi$  is known from (39) and our discussion of the asset motive which derives solely from the complementarity effect of resource supply on capital return  $F_{tKR}$  in section 3.3.1 where we notably based our analysis on exactly the same reference extraction path  $(R_1^{N*}, R_2^{N*})$  according to (21) as in the scenario comparison at hand. Since the omniscient monopolist explicitly internalizes the feedback effect from capital accumulation (cf. section 3.5.1), the neutrality condition relative to the purely naive monopolist is modified for the omniscient monopolist by including the parameter  $\Psi$ .

The interpretation of neutrality condition (48) and the conclusion about the extraction



incentives of the omniscient monopolist in comparison with the purely naive monopolist is completely analogue to section 3.3.1. Still, neutrality condition (48) illustrates that the extraction decision of the omniscient monopolist is characterized by the interaction of the asset motive (with its partial and general equilibrium components) and the addiction motive. Due to the ambiguity of  $\Psi$  and the ambiguity of the partial equilibrium asset motive which we observed in section 3.3.1 we may in principle get any ordering of the supply scenarios of the purely naive monopolist, the naive monopolist with asset motive and the omniscient monopolist, depending on the relative weights of the different motives. Our previous results, however, allow us to draw the following conclusions about the ordering and the relationship of scenarios  $N$ ,  $NA$  and  $GA$  in equilibrium:

- When we evaluate neutrality condition (48) and the sign of  $\Psi$  for the optimal extraction path  $(R_1^{N*}, R_2^{N*})$  in scenario  $N$ , we still generally cannot draw any conclusion whether the omniscient monopolist extracts more or less conservationist than the naive monopolist with assets. The only exception is the special case when scenarios  $N$  and  $NA$  coincide ( $\frac{s_{1E}}{s_{0E}} = \Phi$ ).
- If  $\Psi = 0$  and  $\frac{s_{1E}}{s_{0E}} = \Phi$ , all three scenarios,  $N$ ,  $NA$  and  $GA$ , coincide, despite very different levels of knowledge.

Similar conclusions are possible regarding scenarios  $N$ ,  $G$  and  $GA$  in equilibrium, because the purely addiction motivated monopolist always chooses a less conservationist extraction policy than the naive monopolist from scenario  $N$ :

- The extraction paths in scenarios  $N$ ,  $G$  and  $GA$  can never coincide at the same time.<sup>31</sup>
- For scenarios  $N$  and  $GA$  to coincide or  $GA$  to be more conservationist than  $N$  (according to (48)), the omniscient monopolist must choose a more conservationist extraction path than the purely addiction motivated monopolist from scenario  $G$  and pursuing the general equilibrium asset motive must induce a postponement of extraction (cf. (47)).

In line with section 3.3.1 and the discussion of neutrality condition (39), the right side of (48) will not change with a redistribution of capital endowments, as the threshold  $\Phi$  remains unaffected. Redistributing capital endowments to country  $E$ , however, will alter the left side and thus the extraction policy of the omniscient monopolist as the

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<sup>31</sup>The same holds true for scenario  $NA$ . If  $\frac{s_{1E}}{s_{0E}} = \Phi$  and the naive monopolists with and without asset motive choose exactly the same extraction path, the monopolist of scenario  $G$  pursuing only the addiction motive will always extract less conservationist.

following proposition summarizes.

**Proposition 11.** *Redistributing capital endowment to country  $E$  will overall increase the speed of extraction by the omniscient monopolist relative to the standard naive monopolist's outcome.*

Following the previous section 3.5.2 we already know that redistributing capital endowment to country  $E$  always gives the omniscient monopolist an incentive to speed up extraction compared to the monopolist pursuing only the addiction motive whose extraction decision does not depend on the distribution of capital endowment. However, since the naive monopolist does not react to any redistribution of the capital endowment either, the omniscient monopolist must accelerate extraction also in comparison with the naive monopolist's outcome and the proposition holds.<sup>32</sup>

#### 3.5.4 Comparison with Competitive Extraction

In the following, we again extend the characterization of the omniscient monopolist's supply decision by comparing it with the competitive supply path and examining whether the omniscient monopolist may reverse the standard textbook conservationist bias of a resource monopolist for  $\sigma < 1$ .

**Proposition 12.** *The omniscient monopolist generally may choose a more or less conservationist extraction path than the competitive market due to the interplay of addiction and asset motive. Iso-elastic resource demand or  $\sigma = 1$  is no longer a sufficient condition for the neutrality of market power with a full level of information.*

Following the reasoning in section 3.3.2 the omniscient monopolist's extraction path will correspond to the competitive outcome if

$$(1 + i_2^{C*})MR_1^{GA} = MR_2^{GA} \quad \text{for the competitive extraction path } (R_1^{C*}, R_2^{C*})$$

---

<sup>32</sup>Proposition 2 showed that increasing first period's asset holdings establishes – except for the special case  $(\Phi < (1 + i_1^{N*}) \frac{\partial s_{1E}}{\partial y_{1E}})$  where the endowment distribution does not influence the effect of the asset motives on the extraction path at all – an incentive for the naive monopolist pursuing an asset motive to speed up extraction, too. Since both extraction policies change, we generally cannot derive any conclusion about the influence of the endowment distribution on the comparison between scenarios  $GA$  and  $NA$  in equilibrium.

or by using (45), (42), (46) and (37) if

$$\hat{\Delta} \equiv \frac{p_2^{C*}}{\sigma} \Delta + \Psi \frac{dK_2}{dR_2} = 0 \quad \text{for the competitive extraction path } (R_1^{C*}, R_2^{C*}). \quad (49)$$

We define the parameter  $\hat{\Delta}$  as the general equilibrium counterpart to  $\Delta$  from (42). In analogy to scenario *NA*,  $\hat{\Delta}$  measures the incentive of the omniscient monopolist to deviate from the competitive outcome. The omniscient monopolist chooses a more conservationist extraction path for  $\hat{\Delta} > 0$  but speeds up extraction relative to the competitive outcome for  $\hat{\Delta} < 0$ .

Obviously, whether the omniscient monopolist deviates from the competitive outcome or not depends on the respective incentive of the naive monopolist with asset motive ( $\Delta$  from (42)) and the influence of the additional considerations which the omniscient monopolist takes into account due to his awareness of the endogeneity of capital accumulation ( $\Psi$  from (46)). If, for example, the share of final goods' production which country *E* can capture as factor remuneration increases over time ( $\Delta > 0$ ) and the naive monopolist with asset motive extracts more conservationist than the competitive market according to (42), the omniscient monopolist will only offset the conservationist extraction bias for  $\Psi > 0$  due to  $\frac{dK_2}{dR_2} < 0$  according to (32). Intuitively, the addition motive must dominate sufficiently the strengthening of the second period's asset motive to establish a sufficient incentive for the omniscient monopolist to speed up extraction compared to the naive monopolist with asset motive.

In general, however, we may have any combination of  $\Delta$  and  $\Psi$  so that the omniscient monopolist can have an incentive to extract faster than the competitive market ( $\hat{\Delta} < 0$ ) even if the scenario *NA* monopolist chooses a more conservationist extraction path ( $\Delta > 0$ ), or vice versa.

For iso-elastic resource demand, i.e. for the case  $\sigma = 1$ , the factor shares  $\theta_{tR}$  and  $\theta_{tK}$  are constant.<sup>33</sup> Nevertheless, since the share of country *E*'s asset holdings in total capital stock  $\frac{s_{tE}}{K_2}$  is likely to change over time so that  $\Delta \neq 0$  and, similarly, since  $\sigma = 1$  does not necessarily imply  $\Psi = 0$ , iso-elastic resource demand no longer is a sufficient condition for the monopolistic outcome to coincide with the competitive outcome.

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<sup>33</sup>Indeed, we have  $\theta_{tR} = \frac{F_{tR}R_t}{F_t} = \lambda \frac{R_t}{F_t} \left( \frac{F_t}{R_t} \right)^{1-\alpha} = \lambda$  and  $\theta_{tK} = \frac{F_{tK}K_t}{F_t} = \gamma \frac{K_t}{F_t} \left( \frac{F_t}{K_t} \right)^{1-\alpha} = \gamma$  according to (3) because  $\sigma = \frac{1}{1-\alpha} = 1$  implies  $\alpha = 0$ .

## 4 Numerical Simulation and Graphical Illustration

To illustrate our results, figure 1 shows the respective paths of the perceived marginal revenue of all four scenarios from a numerical simulation. The curves show the resulting manifestations of the effects that the respective monopolist considers in the model for the exemplary parameters  $\sigma \approx 0.91$  (high but below 1),  $\eta = 2$ ,  $\beta = 0.3$ ,  $\lambda = 0.1$ ,  $\gamma = 0.4$ ,  $A = 300$  and the exemplar endowments  $K_1 = 200$ ,  $s_{0E} = 20$ ,  $s_{0I} = 180$ ,  $\bar{R} = 10$ . I.e. we construct figure 1 by exogenously varying the extraction path within the limits of the given resource stock and by calculating the extended marginal resource revenues  $MR_t$  and the corresponding endogenous variables. The conditional market equilibrium holds along these marginal revenue curves which implies that the capital stock and the interest rate  $i_2$  change along the curves. In particular, there is a unique and specific second period capital stock for the extraction paths feasible within the given resource constraint. The width of the diagram is defined by the resource stock available so that we can include both sides of the respective Hotelling condition into one figure. The overall equilibrium and optimal extraction path is obviously defined by the point of intersection of the first and the second period marginal revenue curves.

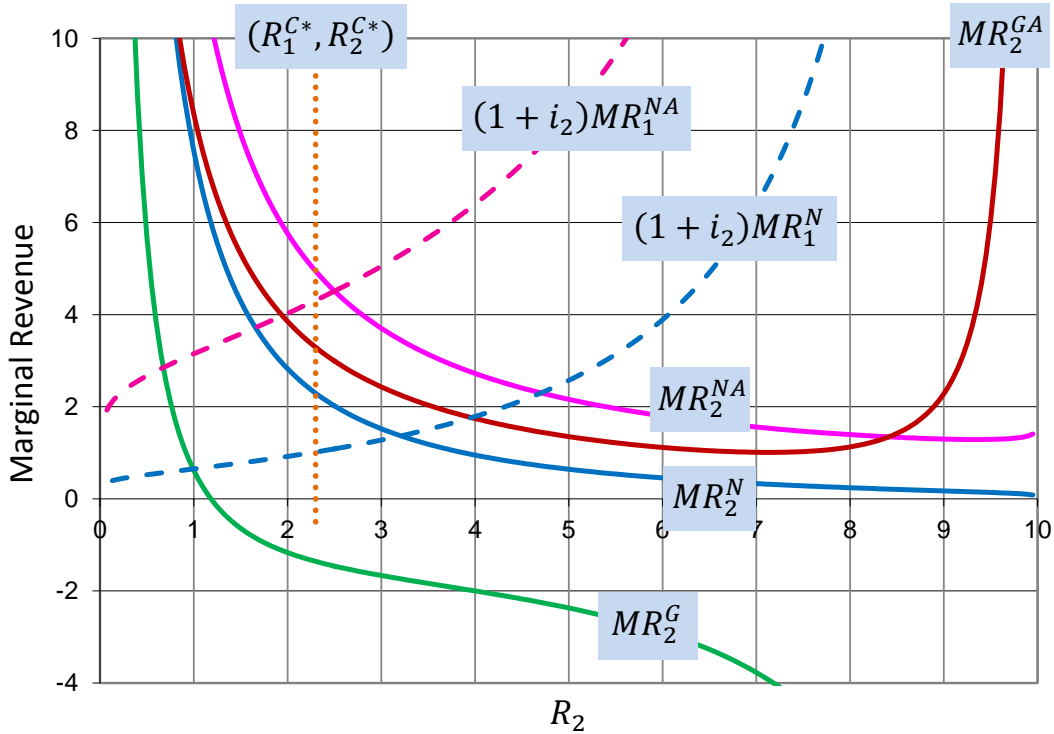


Figure 1: Marginal revenues for all four analyzed scenarios in comparison

Compared to scenario  $N$ , the asset motive of scenario  $NA$  induces the monopolist to speed up extraction. The vertical difference between the revenue curves exactly measures the influence of the asset motive. In scenario  $NA$ , the second-period marginal revenue curve with assets does indeed not fall monotonously in  $R_2$  but exhibits a slightly upward sloping part for high values of  $R_2$ , which illustrates the analytical ambiguity of the second period marginal revenue in scenario  $NA$ , that results from the asset motive in general equilibrium. An even stronger upward sloping part due to an enhanced asset motive is visible for scenario  $GA$ . Such an upward sloping part is more likely with higher capital endowments to country  $E$ , which also tends to accelerate extraction *ceteris paribus*.

In scenario  $G$  the monopolist speeds up extraction compared to the standard monopoly case due to the addiction motive. If we compare the shape of both marginal revenue curves  $MR_2^N$  and  $MR_2^G$ , the figure also demonstrates the influence of the capital accumulation feedback on the marginal revenue  $MR_2^G$ . While  $MR_2^G$  strongly declines for high  $R_2$  due to the internalization of the increasingly strong feedback effects from capital accumulation, these effects are overcompensated in scenario  $GA$  by the asset motive related general equilibrium effects.

The conservationist extraction bias from naive monopoly power relative to the competition case is dampened by the asset motive in scenario  $NA$  ( $\Delta > 0$ ) and even reversed for the omniscient monopolist ( $\hat{\Delta} < 0$ ) and the monopolist in the addiction scenario  $G$ .

## 5 The Role of the Elasticity of Substitution $\sigma$

As the interplay of the resource market and the capital market is the central field of analysis in our paper, a change in the substitution parameter is of direct importance for the considered effects. In the following we use the numerical simulation to vary the elasticity of factor substitution, discuss the impact on the equilibrium outcomes of the different scenarios and thus to elaborate on the role of the substitution elasticity in our model.

### 5.1 Influence of $\sigma$ on the Equilibrium Extraction Path

The influence of the elasticity of substitution on the equilibrium extraction paths in all four treated monopoly cases and in the competition case is visible in figure 2. Evidently,

it varies substantially.

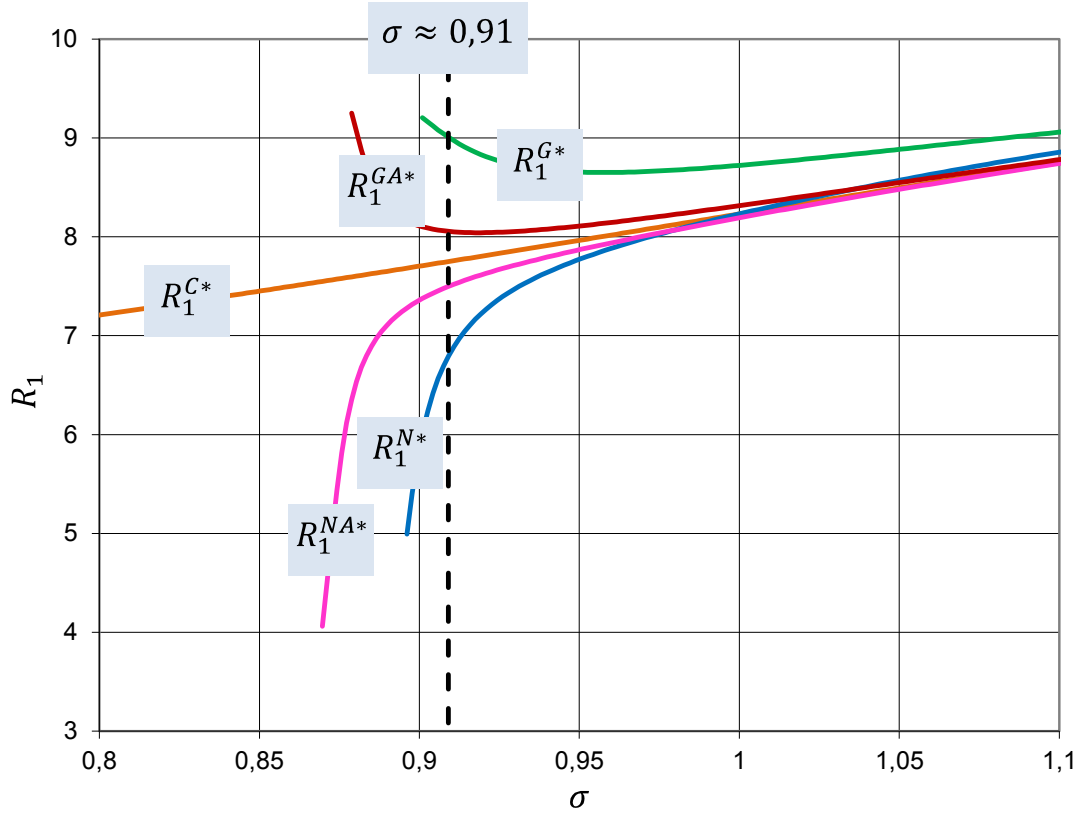


Figure 2: Dependence of the equilibrium present extraction rates on the elasticity of substitution  $\sigma$  between  $R$  and  $K$

The dashed vertical line marks the value of approximately  $\sigma = 0.91$ , which was used in the numerical simulation of the scenarios above. The order of scenarios is mostly constant over the range of  $\sigma$ , but we see two intersection points for  $\sigma \leq 1$ : As mentioned in section 3.2, the equilibrium extraction path of the naive monopoly case  $N$  coincides with the one of the competition case for  $\sigma = 1$  (isoelastic resource demand). And the second intersection is between cases  $N$  and  $NA$  (at roughly  $\sigma = 0.98$ ). This is the point where the asset motive as described in section 3.3.1 is exactly neutral and does not lead to any extraction shift at all, compared to scenario  $N$ .<sup>34</sup>

The curves of the monopoly cases in figure 2 all end between  $\sigma = 0.87$  and  $\sigma = 0.91$ . While  $\sigma$  is falling, the marginal revenues of all cases are going down, finally reaching zero at the end of the respective curve. For lower values of  $\sigma$  the marginal revenue would become negative and the optimization problem changes in the way that it becomes

<sup>34</sup>Keep in mind here, that the neutrality threshold  $\Phi$  and the level of savings  $s_{1E}$  depend on  $\sigma$  themselves.

favorable for the monopolist to leave some resource in the ground. This regime change is beyond the scope of this paper. The marginal revenue in the competitive case goes down as well, but it can never hit zero, since the marginal products with a CES production function are always positive.

## 5.2 Present Extraction Falling with a Decrease in $\sigma$

A reduction in the substitution elasticity obviously causes a decrease in the present extraction rate  $R_1$  in the competitive case. And since this effect is transmitted over the marginal product of the resource in each period, which plays a prominent role in every modification of the Hotelling rule, it affects the four monopoly cases as well. For higher values of  $\sigma$  all scenarios exhibit mostly the same extraction shift to the future as  $\sigma$  goes down. But for lower values of  $\sigma$  mechanisms, which cause the divergence of the scenario outcomes (discussed in the next section), more and more dominate the pure extraction shift to the future. First of all, with a decrease in  $\sigma$ , all marginal products are reduced. But in the competitive case the first period's marginal revenue in current terms  $(1 + i_2)p_1$  experiences a stronger reduction through the movement in both,  $i_2$  and  $p_1$ , than the second period's marginal revenue  $p_2$ , although  $p_1$  alone goes down less than  $p_2$ . As a result, the extraction path shifts towards the higher marginal revenue in the future.

## 5.3 Divergence of Scenarios with a Reduction in $\sigma$

Another striking feature of the plot is the increasing divergence of the scenario outcomes with sinking values for  $\sigma$ . While the difference between the cases for  $\sigma > 1$  is almost negligible (except for scenario  $G$ , whose addiction motive (see section 3.4.1) is persistent), it grows substantially for lower  $\sigma$ . This divergence is explained by two factors: An accelerated extraction shift to the future in the 'naive' scenario  $N$  and an increasing shift to the present in scenario  $G$ . The scenarios  $NA$  and  $GA$  exhibit additional deviations from their 'base cases'  $N$  and  $G$  due to the asset motive, but do not change the divergence finding dramatically.

As we have already seen in section 3.2, the naive monopoly scenario  $N$  generally features a more conservationist extraction path compared to the competition case. But this difference increases with a falling substitution elasticity  $\sigma$ . When monopoly power is 'switched on' in the competitive equilibrium, then the resulting imbalance in the

monopolist's Hotelling rule must be sorted out through an extraction shift to the future and the according adjustment of both periods' marginal revenues. However, the adjustment reaction of the marginal revenue depends itself on  $\sigma$  (cf. (23) and (34)).

While  $\frac{dp_2}{dR_2}$  is the reaction function of the marginal revenue of the competitive case to a shift in  $R_2$ , the factor in front of it falls almost linearly with a reduction in  $\sigma$  until it reaches zero shortly below  $\sigma = 0.9$ . As a result, the extraction shift, that is necessary to achieve a certain movement of the marginal revenue in the monopoly case, rises approximately in a hyperbolic manner, as we see in figure 2 for the curve of scenario  $N$ .<sup>35</sup>

On the other hand, the curves of scenario  $G$  and of the full general equilibrium case  $GA$  are convex and a reduction in  $\sigma$  prompts a smaller postponement of extraction than we see in the competitive case and, finally, even an increase in present extraction, when further reducing the elasticity of substitution. The addiction motive, as it is described in section 3.4.1, is reinforced through the reduction in  $\sigma$ . The corresponding negative term  $\frac{\partial p_2}{\partial R_2} \frac{dK_2}{dR_2} R_2$  in this scenario's marginal revenue is increased in absolute terms. This fast growth in the addiction motive obviously overcompensates the extraction postponement of the scenarios  $N$  and  $NA$ , that follows from the reduction in  $\sigma$ , in this simulation example and leads to ever higher extraction rates in the present, the further the elasticity of substitution is reduced. As we have seen in 3.4.2, while the outcome of scenario  $G$  always exhibits a higher present extraction than the naive monopoly of scenario  $N$ , it does not necessarily have to feature even a higher present extraction than the competition case, but can rather also lie between the outcomes of scenario  $N$  and competition.

## 6 Conclusion

We provide an analysis of monopoly power on the market for a crucial resource like oil in general equilibrium with elastic demand. The formal analysis is enhanced with a numerical simulation of the model. Our model framework takes the impact of oil extraction on the endogenous interest rate, output and capital accumulation into account, as well as the resulting complex effects on resource demand and again on the

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<sup>35</sup>The  $\sigma$ -depending factor in (23) and (34), that dampens the necessary adjustment reaction of the monopolist's marginal revenue, is overlain by the increasing demand elasticity  $\frac{\partial \epsilon}{\partial R_2} > 0$  in equation (27) during the extraction shift, that increases the effect of a shift in  $R_2$  on  $MR_2^N$  and thus alleviates the adjustment of the monopolist's Hotelling rule. However, this alleviation melts down itself with a reduction in  $\sigma$ , so that a low  $\frac{dMR_2^N}{dR_2}$  remains.



interest rate. As a central contribution of the paper, we find that the monopolist's level of knowledge about the different effect channels, feedback effects and economic structures in the general equilibrium setup is crucial for his choice of the optimal extraction path from his respective view. We change his level of awareness in steps to define and analyze four scenarios and to make the influence of different parts of the monopolist's knowledge on his resource extraction decision more transparent. Finally, the scenario *GA* incorporates complete knowledge about the whole economic structure on the side of the monopolist and constitutes a case of comprehensive general equilibrium resource monopoly.

In the naive monopoly case (scenario *N*), as in a partial equilibrium model, where the monopolist only knows the resource demand behavior, monopoly power leads to a postponement of extraction if the according competitive extraction path is falling over time and capital accumulation is positive. This classical conservationist bias of the monopoly, however, is put in question as the extraction shift of the monopolist relative to the competitive outcome becomes ambiguous if capital accumulation is negative, or if the competitive extraction path is upward sloping (due to high enough positive capital accumulation).

Knowledge about the impact of resource extraction on the capital accumulation dynamics and the resulting changes in resource demand in scenario *G* lead to the emergence of an unambiguous 'addiction motive': Taking into account this aspect of interconnectedness of the capital market and the resource market, the monopolist is less conservationist than the naive monopolist of scenario *N* and shifts the extraction path to the present (for  $\frac{dK_2}{dR_2} < 0$ ). The higher resource supply in the present leads to more output and capital accumulation in the present and a higher dependence on the resource in the future, that can be exploited strategically by the exporter. The strength of the addiction motive in the monopolist's considerations depends on the relationship between changes in resource extraction in period 1 and the resulting changes in resource demand (via capital accumulation) in period 2. This acceleration of extraction due to general equilibrium knowledge can even lead to faster extraction under monopoly than in the perfect competition case, so that Robert Solow's (1974) dictum of the monopolist being 'the conservationist's friend' can be reversed. Also, it is possible that the monopolist chooses the social optimum extraction path of the competition case. Moreover, even for an isoelastic resource demand (i.e. elasticity of substitution between capital and resource  $\sigma = 1$ ) the extraction shift to the present persists and the resulting extraction paths of monopoly and competitive case cease to be identical, in contrast to the usual partial equilibrium setup.

Another striking result of our analysis of resource market power in general equilibrium is the emergence of what we call the 'capital asset motive'. The investment of a part of the resource revenues from period 1 leads to the build up of a capital asset stock by the resource exporting country, akin to the recycling of petrodollars and the creation of sovereign wealth funds and other capital deposits, that we have seen in the last decades by many OPEC countries. As a result, returns on capital investments are added as a second income source and the role of the classical resource monopolist, as he is known from the literature, changes to that of a simultaneous resource extractor and capital investor. In scenario *NA* the monopolist first knows about his direct power over the future interest rate and then, in scenario *GA*, even about the whole capital market dynamics, which affect his capital income. Taking this asset motive into account can shift the monopolist's optimal extraction path to the future or to the present. The direction of the shift depends on the initial capital endowments and on the rate of growth of the resource exporting country's share in the world capital asset stock. Put differently, the relative 'strength' of the asset motive in both periods determines the direction of the extraction shift. In scenario *GA* with its full general equilibrium dynamics being considered by the monopolist, the future period's asset motive is stronger than in scenario *NA* with its lower level of the monopolist's awareness. Thresholds for the change in direction of the extraction shift when switching from one scenario to another are provided. Another interesting phenomenon, for both scenarios *NA* and *GA*, is that the monopolist's marginal resource revenue in period 2 can develop an area with a positive slope in resource extraction  $R_2$ , in contrast to the normal falling marginal revenue in a case without an asset motive. The conclusions that we draw in the different sections, however, refer to constellations where the marginal revenue curves in both periods fall in a conventional manner.

The analysis of the strategic capital asset motive makes dynamic changes in the role of a resource exporter with market power visible. Starting as a pure resource exporter, the monopolist over time turns into a capital investor with influence on the capital market via his resource market power. The pure resource revenues may become secondary during this process. A change of strategic incentives and political priorities of OPEC countries over the decades in their competition with industrialized countries in the political arena can be made plausible in this way.

Both, the asset motive and the addiction motive constitute different aspects of the mutual dependency of oil exporters and importers. The industrialized countries are not simply at the exporter's mercy, but the monopolist's interest in the importing countries' prosperity is at the least twofold: On the one hand, the exporter wants to maintain and

increase the importers' 'oil addiction' for the future. On the other hand, he does not want to jeopardize his capital asset returns. The general equilibrium perspective has proven very useful for gaining insights, not only into the strategic relation of resource exporters and importers, but also into the complex interlocking of capital and resource markets (especially for oil). Our analysis thus contributes to a better understanding of the supply motives and strategies of suppliers of fossil energy resources and of the conditions of successful climate policy.

## A Appendix: Capital Supply

### A.1 Sign of $\frac{dK_2}{dR_2}$

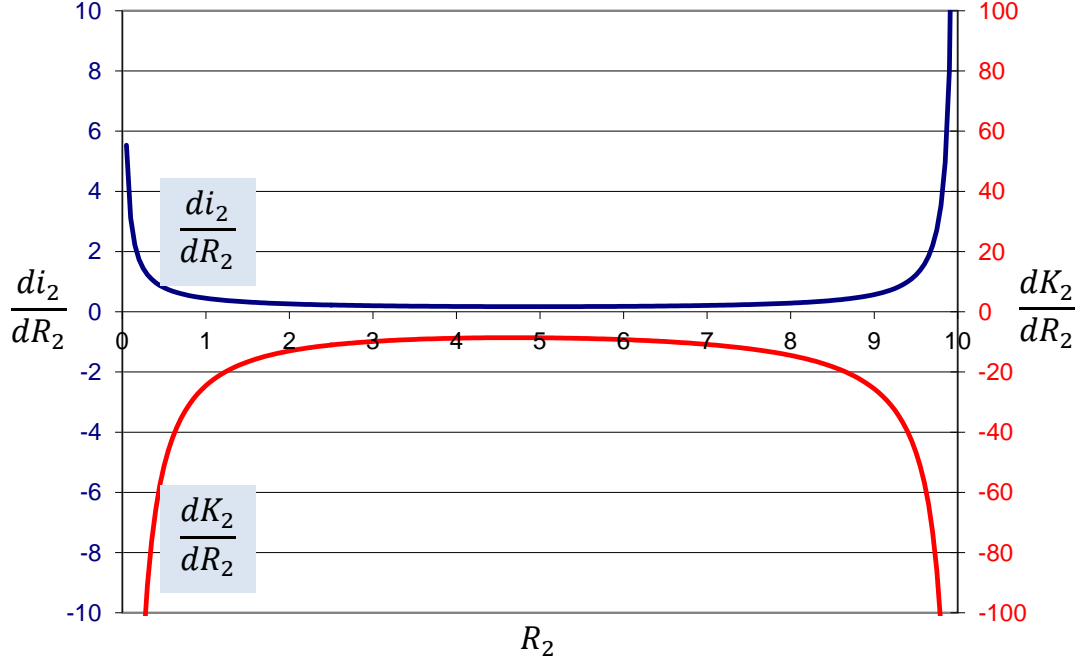


Figure 3: Reaction of the capital stock and the interest rate to a change in  $R_2$  over the extraction rate  $R_2$  for parameter values  $\sigma \approx 0.9$ ,  $\eta = 2$ ,  $\beta = 0.3$ ,  $\lambda = 0.1$ ,  $\phi = 0.4$ ,  $K_1 = 200$ ,  $\bar{R} = 10$ .

## B Appendix: Scenario Analysis

### B.1 Scenario NA

#### B.1.1 Relationship of capital endowment $s_{0E}$ and savings $s_{1E}$ in country E

We show in the following, that savings  $s_{1E}$  are linearly increasing in capital endowment if capital endowments are redistributed from country  $I$  to country  $E$  for a given extraction path and a given overall first period capital stock  $K_1$ .

Due to our assumption of symmetric homothetic preferences, overall capital accumulation is just a function of the extraction path and the first period capital stock  $K_1$ . This

implies that for any given extraction path the interest rates in both periods  $i_1, i_2$  and the period resource income streams  $\pi_{1E}, \pi_{2E}$  are determined and independent of any redistribution of capital endowment. In contrast, overall first period household income  $y_{1E}$  still depends on the capital endowment  $s_{0E}$ .

For a given extraction path and given  $K_1$ , we therefore can decompose savings as a function of endowments

$$s_{1E}(s_{0E}) = s_{1E}(0) + \frac{\partial s_{1E}}{\partial s_{0E}} s_{0E} = s_{1E}(0) + \frac{\partial s_{1E}}{\partial y_{1E}} \frac{\partial y_{1E}}{\partial s_{0E}} s_{0E} = s_{1E}(0) + \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) s_{0E} \quad (50)$$

where the marginal savings propensity with respect to increases in first period household income,  $\frac{\partial s_{1E}}{\partial y_{1E}}$ , is a positive constant (again greater or lower than unity).

Using this functional relationship, we observe from

$$\left. \frac{\partial \frac{s_{1E}}{s_{0E}}}{\partial s_{0E}} \right|_{K_1, R_1, R_2} = \frac{1}{s_{0E}} \left[ \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) - \frac{s_{1E}}{s_{0E}} \right] = -\frac{s_{1E}(0)}{s_{0E}^2} < 0$$

that the ration of asset holdings falls upon redistributing capital endowment to country  $E$ . Moreover, we can characterize the influence of an (*ceteris paribus*) increase in endowment  $s_{0E}$  on the ratio of second to first period capital holdings by considering the limits

$$\begin{aligned} \lim_{s_{0E} \rightarrow 0} \left. \frac{s_{1E}}{s_{0E}} \right|_{K_1, R_1, R_2} &= \lim_{s_{0E} \rightarrow 0} \left[ \frac{s_{1E}(0)}{s_{0E}} + \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) \right] = +\infty \\ \lim_{s_{0E} \rightarrow \infty} \left. \frac{s_{1E}}{s_{0E}} \right|_{K_1, R_1, R_2} &= \lim_{s_{0E} \rightarrow \infty} \left[ \frac{s_{1E}(0)}{s_{0E}} + \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) \right] = \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) \\ \lim_{s_{0E} \rightarrow K_1} \left. \frac{s_{1E}}{s_{0E}} \right|_{K_1, R_1, R_2} &= \frac{s_{1E}(K_1)}{K_1} = \frac{s_{1E}(0)}{K_1} + \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) > \frac{\partial s_{1E}}{\partial y_{1E}} (1 + i_1^{N*}) \end{aligned} \quad (51)$$

## B.2 Scenario G

### B.2.1 Slope of Marginal Revenue Curve

While the marginal revenue curve of period 1 does not differ from scenario N and is falling monotonously, the slope of the marginal revenue curve in period 2 is ambiguous:

$$\begin{aligned}
\frac{dMR_2^G}{dR_2} &= \frac{\partial MR_2^N}{\partial R_2} \Big|_{K_2} + \frac{\partial MR_2^N}{\partial K_2} \Big|_{R_2} \frac{dK_2}{dR_2} + \frac{\partial p_2}{\partial K_2} \frac{dK_2}{dR_2} + \frac{\partial^2 p_2}{\partial K_2 \partial R_2} R_2 \frac{dK_2}{dR_2} \\
&\quad + \frac{\partial^2 p_2}{(\partial K_2)^2} R_2 \left( \frac{dK_2}{dR_2} \right)^2 + \frac{\partial p_2}{\partial K_2} R_2 \frac{d^2 K_2}{(dR_2)^2} \\
&= \frac{dMR_2^N}{dR_2} + \frac{2-\sigma}{\sigma} F_{2KR} \left[ \left( \theta_{2R} - \frac{1-\sigma}{2-\sigma} \right) + \left( \theta_{2K} - \frac{1}{2-\sigma} \right) \frac{R_2}{K_2} \frac{dK_2}{dR_2} \right] \frac{dK_2}{dR_2} \\
&\quad + F_{2RK} R_2 \frac{d^2 K_2}{(dR_2)^2}
\end{aligned} \tag{52}$$

with  $\frac{dMR_2^N}{dR_2}$  from (34) and  $\frac{dp_2}{dR_2}$  from (17) reveals that the ambiguity arises only from the term  $\frac{d^2 K_2}{(dR_2)^2}$  whereas all the other terms are analytically of negative sign for  $\frac{dK_2}{dR_2} < 0$  and  $MR_2^N > 0$ .<sup>36</sup>

### B.2.2 Scenario G vs. Competition - Reversal of Conservationist Bias

The addiction motive may even reverse the naive conservationist bias (for  $\sigma < 1$ ), if it is sufficiently strong. To show this assume that the optimal competitive extraction path  $(R_1^{C*}, R_2^{C*})$  – even with capital accumulation – falls over time so that  $R_1^{C*} > R_2^{C*}$  and the standard monopolist chooses a more conservationist extraction policy due to the more price elastic demand in the second period.<sup>37</sup> The addiction motive will induce the monopolist to speed up extraction compared to the competitive outcome if the evaluation of the Hotelling rule (43) for the competitive extraction path yields

$$(1 + i_2^{C*}) MR_1^N(R_1^{C*}, R_2^{C*}) > MR_2^G(R_1^{C*}, R_2^{C*})$$

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<sup>36</sup>  $MR_2^N > 0$  ensures that  $\frac{\partial MR_2^N}{\partial R_2} < 0$  (cf. (23)),  $\frac{\partial MR_2^N}{\partial K_2} > 0$  (cf. (24)) and  $\left( \theta_{2R} - \frac{1-\sigma}{2-\sigma} \right) + \left( \theta_{2K} - \frac{1}{2-\sigma} \right) \frac{R_2}{K_2} \frac{dK_2}{dR_2} > 0$  because by combining  $\theta_{2R} > 1 - \sigma$  from  $MR_2^N > 0$  and  $\theta_{2R} + \theta_{2K} < 1$  by the Euler theorem we have  $\theta_{2R} > \frac{1+\sigma}{2-\sigma} > \frac{1}{2-\sigma}$  and  $\theta_{2K} < \frac{1}{2-\sigma}$  at least for  $\sigma < 2$ .

<sup>37</sup> i.e. we have  $|\epsilon_{R_2, p_2}| > |\epsilon_{R_1, p_1}|$  for the falling competitive extraction path due to  $\sigma < 1$  and (28) and (30).

By using the definition of the respective marginal revenue from (22) and (44) as well as the definition of the (standard partial) price elasticity of demand in (27), this inequality will only arise if

$$-\frac{dK_2}{dR_2} \frac{R_2^{C*}}{K_2(R_1^{C*}, R_2^{C*})} > \frac{\theta_{2R}(R_1^{C*}, R_2^{C*}) - \theta_{1R}(R_1^{C*}, R_2^{C*})}{\theta_{2K}(R_1^{C*}, R_2^{C*})} \quad (53)$$

Note that the right side is positive because  $\theta_{2R}(R_1^{C*}, R_2^{C*}) > \theta_{1R}(R_1^{C*}, R_2^{C*})$  directly follows from the definition of the price elasticity of demand (27) and  $|\epsilon_2| > |\epsilon_1|$  which ensures that the naive monopolist indeed postpones extraction compared to the competitive outcome. For  $\sigma\eta > 1$ , we know that the left side is also positive according to (32). Obviously, the addiction motive will induce the monopolist to speed up extraction compared to competitive extraction only for a sufficiently high sensitivity of second period capital stock to changes in the resource extraction path which is measured in (53) by the elasticity of the second-period capital stock with respect to a postponement of extraction<sup>38</sup> if demand is not iso-elastic and  $\sigma < 1$ . Note that the sensitivity of second period capital stock does in the end depend on the consumption preferences in both countries and the production structure given by the CES-technology (3).

Such a sufficiently high sensitivity of the second period capital stock as defined by (53) in turn implies that second period demand is less price elastic in terms of the total price elasticity  $e_{R_2, p_2}$  than first period demand for the competitive supply path  $(R_1^{C*}, R_2^{C*})$ , i.e. that

$$|e_{R_2, p_2}(R_1^{C*}, R_2^{C*})| < |e_{R_1, p_1}(R_1^{C*}, R_2^{C*})|$$

At the same time, we still have  $|e_{R_2, p_2}| > |e_{R_1, p_1}|$  for  $(R_1^{C*}, R_2^{C*})$  due to our assumption that the naive monopolist postpones extraction compared to the competitive market solution (thereby introducing the conservationist bias).

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<sup>38</sup>i.e. a change in the resource extraction path by shifting resources from the first to the second period.

### B.3 Scenario GA

#### B.3.1 Sign and Slope of the General Equilibrium Feedback Effect $\Psi$

The total general equilibrium feedback effect  $\Psi$  from (46) changes with the extraction path ambiguously. This can be observed from the total derivative

$$\frac{d\Psi}{dR_2} = \frac{\partial\Psi}{\partial R_2} \Big|_{K_2, s_{1E}} + \frac{\partial\Psi}{\partial K_2} \Big|_{R_2, s_{1E}} \frac{dK_2}{dR_2} + \frac{\partial\Psi}{\partial s_{1E}} \Big|_{R_2, K_2} \frac{ds_{1E}}{dR_2} \quad (54)$$

where we use for abbreviation

$$\frac{\partial\Psi}{\partial R_2} \Big|_{K_2, s_{1E}} = \frac{2-\sigma}{\sigma} F_{2KR} \left[ \theta_{2R} + \theta_{2K} \frac{s_{1E}}{K_2} - \frac{s_{1E}}{K_2} - \frac{1-\sigma}{2-\sigma} \left( 1 - \frac{s_{1E}}{K_2} \right) \right] = \frac{\partial MR_2^{NA}}{\partial K_2} \Big|_{R_2, s_{1E}} \quad (55)$$

$$\frac{\partial\Psi}{\partial K_2} \Big|_{R_2, s_{1E}} = \frac{1}{\sigma} \frac{F_{2K}}{K_2} \left[ \frac{2-\sigma}{\sigma} \left( \theta_{2K} - \frac{1}{2-\sigma} \right) \left( \theta_{2R} + \theta_{2K} \frac{s_{1E}}{K_2} - \frac{s_{1E}}{K_2} \right) + (1 - \theta_{2K}) \frac{s_{1E}}{K_2} \right] \quad (56)$$

which implies that if either  $\sigma \geq 2$  or  $\sigma < 2$  and  $\theta_{2K} < \frac{1}{2-\sigma}$ , then  $\frac{\partial\Psi}{\partial K_2} \Big|_{R_2, s_{1E}} > 0$  whenever  $\frac{\partial\Psi}{\partial R_2} \Big|_{K_2, s_{1E}} < 0$ . Note that  $\theta_{2K} < \frac{1}{2-\sigma}$  holds due to the Euler theorem at least as long as  $MR_2^N > 0$ .

Finally we have

$$\frac{\partial\Psi}{\partial s_{1E}} \Big|_{R_2, K_2} = F_{2KK} \quad (57)$$

The first two terms in (54) are ambiguous because  $\theta_{2R} + \theta_{2K} \frac{s_{1E}}{K_2} - \frac{s_{1E}}{K_2}$  or, equivalently,  $\Psi$  is of ambiguous sign, in general.<sup>39</sup> The last term is ambiguous due to the generally ambiguous savings reaction. In general, therefore,  $\Psi$  may change sign when redistributing

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<sup>39</sup> $\Psi$  may also be stated as

$$\Psi = \frac{F_{2K}}{\sigma} \left[ \theta_{2R} + \theta_{2K} \frac{s_{1E}}{K_2} - \frac{s_{1E}}{K_2} \right]$$

by use of the CES-technology (3) and the resource and capital market equilibrium conditions  $p_t = F_{tR}$  and  $i_t = F_{tK}$ .  $\Psi > 0$  therefore also implies that the share of total output which country  $E$  can capture as factor remuneration exceeds its share in the second period capital stock, and the other way round. Moreover, note that  $\theta_{2K} - \frac{1}{2-\sigma} < 0$  for  $\sigma < 2$  and  $MR_2 > 0$  from (36).



resources from one period to another so that  $MR_2^{GA}$  and  $MR_2^{NA}$  intersect.

### B.3.2 Slope of $MR_2^{GA}$

Recall that by (20), (36) and (46) we have

$$\begin{aligned}
MR_2^{GA} &= MR_2^{NA} + \Psi \frac{dK_2}{dR_2} \\
\frac{dMR_2^{GA}}{dR_2} &= \frac{dMR_2^{NA}}{dR_2} + \frac{d\Psi}{dR_2} \frac{dK_2}{dR_2} + \Psi \frac{d^2K_2}{(dR_2)^2} \\
&= \underbrace{\frac{\partial MR_2^{NA}}{\partial R_2} \Big|_{K_2, s_{1E}}}_{<0 \text{ for } MR_2^{NA} > 0 \text{ ((??))}} + \underbrace{\frac{\partial MR_2^{NA}}{\partial K_2} \Big|_{R_2, s_{1E}} \frac{dK_2}{dR_2}}_{1 \text{ from (??)} < 0} + \underbrace{\frac{\partial \Psi}{\partial R_2} \Big|_{K_2, s_{1E}} \frac{dK_2}{dR_2}}_{2 \text{ from (55)} < 0} \\
&\quad + \underbrace{\frac{\partial \Psi}{\partial K_2} \Big|_{R_2, s_{1E}} \left( \frac{dK_2}{dR_2} \right)^2}_{3 \text{ from (56)} > 0} + \underbrace{\frac{di_2}{dR_2} \frac{ds_{1E}}{dR_2}}_{>0 \text{ from (18)} \gtrsim 0} + \underbrace{\Psi \frac{d^2K_2}{(dR_2)^2}}_{\gtrsim 0 \text{ from (46)} \gtrsim 0}
\end{aligned} \tag{58}$$

Overall, the total derivative is of ambiguous sign. In addition to the terms where we already indicated the ambiguity note that, even though the omniscient monopolist will never choose a supply path for which  $MR_t^{GA} < 0$ ,  $MR_2^{NA} > 0$  does not necessarily hold if  $\Psi < 0$  (see (45) and (46)). Moreover, the terms 1, 2 and 3 are generally of ambiguous sign due to (55) and (56) from appendix B.3.1. Finally, the overall ambiguity of the total derivative above is also due to the ambiguous savings reaction  $\frac{ds_{1E}}{dR_2}$  from (??), which also complicated the analysis in scenario  $NA$ , and due to the ambiguity of  $\frac{d^2K_2}{(dR_2)^2}$ , which is already pointed out in section 3.4 when we analyze the slope of the addiction-motivated monopolist's marginal revenue curve of the second period (see (52) in section B.2.1).

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