DISCUSSION PAPER SERIES

Discussion paper No.86

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March 2012

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SCHOOL OF ECONOMICS

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Does the Acquisition of Mines Benefit Resource-Importing Countries?*

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Version: March 12, 2012

Abstract

Using a simple two-period model, this paper examines the effects of the acquisition of mines/resources by a final goods producer located in a resource-importing country on resource prices in both the first (the present) and second (the future) periods, profits of firms, and welfare. We find that an increase in the mines owned by a final goods producer can increase the resource price in the first period and/or, interestingly, the second period. The strategic behavior of a resource-extracting firm located in a resource-exporting country produces this result. Whether the resource price increases in either period depends on the demand structure for the final goods and the resource supply condition of the final goods producer which owns the mines in the second period. We also consider three extended situations: joint exploration, entry of speculators, and the case of a non-committed investment.

Keywords: Acquisition of mines, resource exploitation, governments' support.

JEL Code: F12, F18, Q31, Q34.

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*The authors are grateful to Morihiro Yomogida and Kozo Kiyota for helpful comments. The authors also gratefully acknowledge financial support from Japan Society for the Promotion of Science under the Grant-in-Aid for Scientific Research (B, 21330067), and Research Institute of Economy, Trade & Industry.

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1 Introduction

Expecting that many types of resources will become scarcer in the near future, intermediate and final goods producers have been competing seriously for stable procurement of resources. The variety of resources that serve as inputs into the production of products has also increased, and products developed over the past few decades increasingly use very scarce resources, such as rare earth metals. For example, nickel, chrome, titanium, and palladium are used to produce cell phones. And, gallium is used to produce light emitting diodes. In some industries, these minor metals are critical for production. Accordingly, the producers of such products, particularly those in resource-importing countries, have increased efforts to acquire these resources.

These mining resources are often unevenly distributed across a small number of countries. Furthermore, resource mines may be owned by a small number of resource-extraction firms called "resource majors." Thus, the concentration ratios of several types of resource markets are very high.[1] In contrast, the number of intermediate/final goods producers is relatively large. Thus, resource-extracting firms have bargaining power when resource prices are being determined.

Given this situation, some final goods producers have begun to acquire and develop their own mines (or oil fields).[2] The governments of resource-importing countries have been supporting these firms by providing capital contributions and/or loans with low interest rates.[3] These policies aim to encourage investment in the search for and acquisition of new mines by domestic final goods producers with a view to achieving stable resource procurement at low prices.

Using a simple two-period model, this paper examines the effects of the acquisition of mines/resources by a final goods producer (home firm) located in a resource-importing

[1] See, for example, the Minerals Yearbook by the United States Geological Survey (USGS) (http://minerals.usgs.gov/minerals/pubs/myb.html) and Strategic Metal Investments Ltd. (SMI Ltd.) (http://www.strategic-metal.com/index.php/news/content/chinas_minor_metals_part1).

[2] Hereafter, we omit "intermediate" and use only "final goods" for simplicity.

[3] See, for example, Challenges and Actions in Economic/Industrial Policies by the Ministry of Economy, Trade and Industry (http://www.meti.go.jp/english/aboutmeti/policy/fy2012/fy2012policies.pdf) and the United States Department of Energy (http://energy.gov/sites/prod/files/piprod/documents/US-Japan_REE_Meeting.pdf).

country (home country) on resource prices in both the first (the present) and second (the future) periods, profits of firms, and welfare. In particular, we focus on a scenario in which support by the home government encourages investment in the acquisition of mines/resources by the home firm.[4] We also distinguish resource-importing countries from a resource-exporting country, and consider the welfare effects for both types of countries.

To this end, we introduce three important features into our model. First, we assume that there is only one resource-extracting firm located in the resource-exporting country in the first period, although the home firm also owns its own mines and extracts resources in the second period. In contrast, there are many final goods producers that use the resource as input. Thus, the resource-extracting firm has the power to determine the resource price in each period. Second, the amount of investment in exploration by the home firm is determined before the first period begins, but the resource can only be extracted in the second period. This setting is representative of the real world, in which it is usually time consuming to explore and acquire new mines. Third, we consider the stock-dependent cost for extraction by the resource-extracting firm (i.e., the variable cost in the second period is higher than in the first period).

Using a cartel-versus-fringe model, Salant (1976) derived equilibrium price and sales paths using a Nash-Cournot approach. He demonstrated that the competitive fringe completes its sales first, although it may benefit from the formation of a cartel. Ulph and Folie (1980) extended the model to the case where firms' costs are heterogeneous.[5] In our model, a competitive fringe exists only in the future period. In this respect, our model is related to that of Gilbert and Goldman (1978). They examined the situation in which potential entrants exist and found that potential competition increases the present resource price set by a monopolist and the entry of competitors is delayed.[6] However, they did not explicitly consider the demand/supply and market structures.

[4]We mainly use "mines" in the following analysis. However, our analysis can be applied to the case of oil fields.

[5]The problem of time-consistency is examined by Groot et al. (2003)

[6]Agee (2000) extended this analysis into the case of private stock information. In terms of changes in market structure, Rötheli (1995) considered the case where there is a possibility of the market being cartelized. Moreover, Hillman and Long (1983) examined the situation where there is the possibility of trade disruption.

Using an oligopoly model, Sadorsky (1992) investigated the determination of both exploration and extraction in the two-period model and examined the effects of changes in the number of firms and quantity tax rate on extraction and exploration. Under a duopoly, Polasky (1996) also considered exploration, examining the problem of private information on exploration. Mason (2010) examined privately held stockpiles of minerals and demonstrated that if extraction costs are stock-dependent and if prices are stochastic and sufficiently volatile, then firms have an incentive to hold inventories in order to streamline production over time. Teisberg (1981) developed a stochastic dynamic programming model and examined the effective stockpile policies of petroleum. Wei et al. (2008) empirically estimated the optimal strategic petroleum reserve for China. However, they do not explicitly consider the relationship between the resource-importing and resource-exporting countries.[7]

Karp and Newbery(1991, 1992) and Chou and Long (2009) examined the optimal policies of resource-importing countries. However, they mainly focus on tariff policies. As far as we know, there are few studies that investigate the price and welfare effects of the acquisition of new mines on resource prices in both the present and future periods by explicitly considering the market structure.

We find that an increase in the number of mines owned by the home firm can increase the resource price in the first period and/or, interestingly, the second period. This finding implies that the total resource consumption in the first or second period may decrease. The strategic behavior of a resource-extracting firm located in a resource-exporting country produces this result. Whether the resource price increases in either period depends on the demand structure for the final good and the supply condition of the resources for the home firm in the second period. Moreover, we consider three extended situations. First, when the home firm and the resource-extracting firm embark on joint exploration, it is more likely that the resource price in the second period will increase in response to an increase in investment in new mines by the home firm. Second, when speculators enter

[7] A body of literature empirically examined the effect of reserve policies on oil prices (see Considine, 2006 and Demirer and Kutan, 2010, for example). They focus on the relatively short run effect on the oil spot and future markets. Yucel (1994) and Ejarque (2010) also examine the resource reserve policies of the U.S. and EU respectively.

the market, the resource prices in both periods change in the same direction. Even in such a case, under certain conditions, prices may increase because of the acquisition of new mines by the home firm. Third, we consider a situation in which the home firm determines its investment amount after the resource-extracting firm chooses the resource price in the second period. We also discuss the welfare effect of the acquisition of new mines on the final goods producer.

The structure of the paper is as follows. Sections 2 and 3 describe the basic model and the equilibrium situation. Section 4 examines the price effects of an increase in the mines/resources owned by a final goods producer. Section 5 examines the welfare effects, and Section 6 considers three extended situations. Section 7 provides concluding remarks.

2 The Basic Model

There is only one resource supplier (Firm f), which is located in the resource-exporting country (Country f). There are n firms that produce final goods X from the resource, which are located in resource-importing countries. One of those final goods producers (Firm h) is located in the home country. The final goods producers including Firm h supply their own products to the integrated world market (see Figure 1 for the structure of the model).

We consider a simple two-period model. In each period, Firm f determines the resource price first. Then, each final goods producer chooses its output. Final good producers compete with each other in a Cournot fashion in the final goods market, while they are price takers in the resource market.[8]

Firm h invests in the exploration of mines, and those mines are ready for extraction when it begins the production of final goods in the second period.[9] However, it is assumed that the amount of extraction from its own mines is smaller than the amount it needs and, therefore, it also purchases resources from Firm f. Furthermore, we do not consider

[8]In the real world, the number of consumers is larger than the number of final goods producers, and the number of final goods producers is generally larger than the number of the resource extracting firms in the case of industries that use the resource as an input. Therefore, this setting is reasonable.

[9]Even if all final goods producers own mines, the same results are obtained. For simplicity of notations and equations, we exclude exploration by other final goods producers.

the effects of uncertainty on exploration. Thus, an increase in investment in exploration implies an increase in the acquisition of new mines.

Firm h determines the amount of investment in exploration before the first period begins. This setting reflects an important aspect of mining investments: it is time consuming to complete the exploration of new mines. We consider that the investment amount is exogenous when the resource price and outputs are determined in both periods.[10]

The world inverse demand curve for the final goods in each period is given by

$$p_{x,j} = P_x(X_j), \quad P_x' < 0, \quad j = 1, 2,$$

the structure of which is fixed through both periods. X_j denotes the total output of final goods in period j.

One unit of final goods X is made from one unit of the resource, and the marginal cost for producing the final goods, except for the resource procurement cost, is assumed to be zero. The profit of each final goods producer i, except for Firm h, in each period is given by:

$$\pi_{i,j} = (p_{x,j} - p_{r,j}) \cdot x_{i,j},$$

where $p_{x,j}$ and $p_{r,j}$ denote the prices of output and the resource in period j $(= 1, 2)$, respectively. Moreover, $x_{i,j}$ denotes the output of each final goods producer (Firm i) in period j.

For Firm h, the profits of both periods are given by

$$\pi_{h,2} = (p_{x,2} - p_{r,2}) \cdot x_{h,2} + p_{r,2} M_h - C_h(M_h, I),$$

$$\pi_{h,1} = (p_{x,1} - p_{r,1}) \cdot x_{h,1},$$

where M_h, C_h, and I denote the amount of extraction by Firm h, the cost of the extraction, and the investment amount for the exploration/acquisition of mines, respectively. The

[10] Even when Firm h determines the amount of investment after the resource prices in both periods are chosen by Firm f, similar results are obtained. However, an additional factor that affects the strategic behavior of Firm f in choosing the resource prices can be observed. We will refer to this situation in Subsection 6.3.

larger the investment is, the more mines Firm h owns in the second period.[11] We assume that $\partial C_h/\partial M_h > 0$, $\partial^2 C_h/\partial M_h^2 > 0$, $\partial C_h/\partial I < 0$, $\partial^2 C_h/\partial I^2 > 0$, and $\partial^2 C_h/\partial I \partial M_h < 0$.

The objective of the final goods producers is to maximize their own profits in each period. Because they are price takers in the resource market, and because none of them have any mines in the first period, they do not consider the effect of their own production in the first period on the resource price in the second period.

We assume that the cost for the resource extracting activity of Firm f is stock dependent. Therefore, the marginal cost curve shifts upward in the second period as compared with the first period. The larger the amount of the extraction in the first period, the greater the shift is. In particular, for the total extraction through the two periods (R_s), the total cost is defined as:

$$TC_r = C_f(R_s), \quad C_f' > 0, \quad C_f^{''} > 0.$$

Thus, the cost function for each period is given by:

$$C_{f,1} = C_f(R_1), \quad C_{f,2} = C_f(R_2 + R_1) - C_f(R_1),$$

where R_j ($j = 1, 2$) denotes the amount of extraction in period j. Note that R_1 is given at the beginning of the second period.

The profit of Firm f in each period is given by:

$$\begin{aligned}
\pi_{f,1} &= p_{r,1} R_1 - C_{f,1}(R_1), \\
\pi_{f,2} &= p_{r,2} R_2 - C_{f,2}(R_2 + R_1) + C_{f,1}(R_1).
\end{aligned}$$

In the second period, Firm f chooses the resource price ($p_{r,2}$) to maximize $\pi_{f,2}$. In contrast to final goods producers, it considers the effect of its choice of resource price in the first period on the situation in the second period. Therefore, Firm f chooses the resource price

[11] The total profit of Firm h is given by

$$\pi_{h,1} - C_I(I, s) + \delta \pi_{h,2},$$

where C_I, s, and δ denote the investment cost, the support by the home government for exploration, such as subsidies, and a discount factor, respectively. We will refer to this total profit when discussing home welfare in Section 5.

in the first period to maximize the total profit:[12]

$$\Pi_f = \pi_{f,1} + \delta \pi_{f,2},$$

where δ is the discount factor. We consider that the discount rate is equal to the interest rate, and accordingly the interest rate is indicated by $(1-\delta)/\delta$.

We consider a general demand curve for the final goods. Therefore, the rate of increase in the optimal resource price for Firm f may be greater than the interest rate. Even in such a case, Firm f is able to choose the resource prices in both periods, if Firm f can prohibit final goods producers from reselling resources to other players, and/or if it is costly for speculators to enter the resource market because of transaction and storage costs. However, in the real world, speculators can enter many resource markets with low entry costs. Therefore, we also consider the case where speculators enter the resource market (in Subsection 6.2), and accordingly, the rate of an increase in the resource price is equal to the interest rate.

The home government may support Firm h's new mine exploration, such as through a subsidy. This support is exogenous in our model, and it is assumed that the government's support always increases the investment in exploration by Firm h.

3 Equilibrium Prices and Extraction

We solve the game by backward induction, and the notion of equilibrium is the subgame perfect Nash equilibrium (see Figure 2 for the structure of the game).

3.1 The Second Period

Final goods producers including Firm h choose outputs to maximize their own profits given the resource price, $p_{r,2}$. The first-order condition (FOC) for each producer is

$$\frac{\partial \pi_{i,2}}{\partial x_{i,2}} = p_{x,2} + P'_{x,2} x_{i,2} - p_{r,2} = 0, \tag{1}$$

[12] If we consider that Firm f simultaneously chooses the resource prices in both periods so that the total profit (Π_f) is maximized, the same equilibrium prices are obtained. However, for clarity of the description of processes and equations, we choose the two step determination of resource prices.

where $P'_{x,2} = P'_x(X_2)$. The second-order condition (SOC) is assumed to hold globally: $\partial^2\pi_{i,2}/\partial x_{i,2}^2 < 0$. Because final goods producers are symmetric except for the acquisition of mines, equilibrium outputs are the same. We define the equilibrium outputs: $\hat{x}_{i,2} = \hat{x}_2 = \hat{x}_2(p_{r,2})$, and $\hat{X}_2 = \hat{X}_2(p_{r,2})$.[13] Then, the FOC ((1)) can be rewritten as

$$P_x(n\hat{x}_2) + P'_x(n\hat{x}_2)\hat{x}_2 - p_{r,2} = 0.$$

The following stability condition is assumed to hold globally: $(n+1)P'_{x,2} + nP''_{x,2}x_2 < 0$, where $P''_{x,2} = P''_x(X_2)$. Therefore, $\partial\hat{x}_2/\partial p_{r,2} < 0$ and $\partial\hat{X}_2/\partial p_{r,2} < 0$ hold.

Firm h also extracts the resource from mines it owns. Because Firm h is a price taker in the resource market, the amount of extraction is determined so that the marginal extraction cost is equal to the resource price: $p_{r,2} = \partial C_h/\partial M_h$. Thus, we obtain the equilibrium amount of extraction: $\hat{M}_h(p_{r,2}, I)$. Note that it follows from the assumption on the shape of C_h that $\partial\hat{M}_h/\partial I > 0$ and $\partial\hat{M}_h/\partial p_{r,2} > 0$.

The demand for the resource extracted by Firm f is given by $R_{D,2}(p_{r,2}, I) = \hat{X}_2(p_{r,2}) - \hat{M}_h(p_{r,2}, I)$. From the shape of the demand and supply curves $(\hat{X}_2, \hat{M}_h)$, it holds that $\partial R_{D,2}/\partial p_{r,2} < 0$. Firm f chooses the resource price in the second period to maximize its profit $(\pi_{f,2})$. The FOC is

$$\frac{\partial\pi_{f,2}}{\partial p_{r,2}} = R_{D,2} + (p_{r,2} - C'_{f,2}) \cdot \frac{\partial R_{D,2}}{\partial p_{r,2}} = 0. \tag{2}$$

The SOC is assumed to be satisfied:

$$\frac{\partial^2\pi_{f,2}}{\partial p_{r,2}^2} = 2\frac{\partial R_{D,2}}{\partial p_{r,2}} - C''_{f,2}\left(\frac{\partial R_{D,2}}{\partial p_{r,2}}\right)^2 + (p_{r,2} - C'_{f,2}) \cdot \frac{\partial^2 R_{D,2}}{\partial p_{r,2}^2} < 0. \tag{3}$$

Thus, we obtain the equilibrium resource price and the supply of the resource by Firm f in the second period: $\hat{p}_{r,2}(R_1, I)$, $\hat{R}_2 = R_{D,2}(\hat{p}_{r,2}, I)$.

3.2 The First Period

The determination of the output quantities of final goods is the same as that in the second period. On the other hand, because Firm h has not yet completed the acquisition of mines, it does not extract resources itself, and accordingly, $R_{D,1}$ is equal to $\hat{X}_1(p_{r,1})$.

[13] These equilibrium variables also depend on the number of final goods producers, n. However, because it does not play any role in our analysis, we omit n from these functions.

Firm f chooses the resource price in the first period to maximize its total profit:

$$\Pi_f = p_{r,1} R_{D,1} - C_{f,1}(R_{D,1}) + \delta \hat{\pi}_{f,2},$$

where $\hat{\pi}_{f,2}$ denotes the equilibrium profit in the second period given R_1. Using the envelope theorem, the FOC is given by:

$$\frac{d\Pi_f}{dp_{r,1}} = R_{D,1} + \left\{ p_{r,1} - (1-\delta)C'_{f,1} - \delta C'_{f,2} \right\} \cdot \frac{\partial R_{D,1}}{\partial p_{r,1}} = 0, \tag{4}$$

where $\partial R_{D,1}/\partial p_{r,1} = \partial \hat{X}_1/\partial p_{r,1}$. For an interior solution for each period to be obtained, the following inequality is assumed to hold.

Assumption 1

$p_{r,1} - (1-\delta)C'_{f,1} - \delta C'_{f,2} > 0.$

Intuitively, Assumption 1 implies that the resource is abundant in the mines owned by Firm f, and accordingly, the marginal cost of extraction for Firm f does not drastically increase. Moreover, the SOC is assumed to be satisfied.[14] Thus, we obtain the equilibrium resource price and extraction amount in the first period: $\hat{p}_{r,1}(I)$, $\hat{R}_1 = R_{D,1}(\hat{p}_{r,1})$.

4 Acquisition of New Mines and Resource Prices

When the home government supports the investments of Firm h, the exploration/acquisition of mines is expected to increase. In this section, we examine the effect of an increase in mines owned by Firm h on the resource prices in both periods.

There are two kinds of effects on resource prices: *the direct price effect* and *the supply-shifting effect*. The direct price effect, which is denoted by $\partial \hat{p}_{r,2}/\partial I$, is the effect of an increase in mines owned by Firm h on the resource price in the second period given the resource supply by Firm f in the first period (R_1).

From (2), we obtain:

$$\frac{\partial^2 \hat{\pi}_{f,2}}{\partial I \partial p_{r,2}} = -\frac{\partial \hat{M}_h}{\partial I} + C''_{f,2} \frac{\partial \hat{R}_2}{\partial p_{r,2}} \frac{\partial \hat{M}_h}{\partial I} - (\hat{p}_{r,2} - C'_{f,2}) \frac{\partial^2 \hat{M}_h}{\partial I \partial p_{r,2}}. \tag{5}$$

[14] Precisely, the SOC is:

$$\frac{d^2\Pi_f}{dp_{r,1}^2} = 2R'_{D,1} + (p_{r,1} - (1-\delta)C'_{f,1} - \delta C'_{f,2}) \cdot R''_{D,1} - ((1-\delta)C''_{f,1} + \delta C''_{f,2}) \cdot R'^2_{D,1} - \delta C''_{f,2} R'_{D,1} \frac{\partial \hat{R}_2}{\partial p_{r,1}} < 0,$$

where $\partial \hat{R}_2/\partial p_{r,1} = \partial \hat{R}_2/\partial p_{r,2} \cdot \partial \hat{p}_{r,2}/\partial R_{D,1} \cdot R'_{D,1}$.

Because $\partial \hat{R}_2/\partial p_{r,2} < 0$ and $\partial \hat{M}_h/\partial I > 0$ hold, we record the following result on the direct price effect.

Lemma 1

If $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$, $\partial \hat{p}_{r,2}/\partial I < 0$ holds. This means that an increase in the investment in new mines by Firm h decreases the resource price in the second period through the direct price effect.

$\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$ means that, the greater amount of mines Firm h owns, the greater is its response to an increase in $p_{r,2}$ by increasing extraction. In other words, the higher the resource price offered by Firm f in the second period is, the greater the effect of an additional unit of investment on the increase in the extraction by Firm h. The shift of the supply curve that satisfies this inequality is shown in Figure 3. As the investment amount increases, the demand for the resource supplied by Firm f becomes more elastic, which gives Firm f an incentive to lower the resource price in the second period.

Now let us turn to the supply-shifting effect. Observing a change in the investment amount by Firm h and expecting a change in the second-period situation, Firm f increases or decreases the resource supply in each period. In other words, Firm f shifts the resource supply from the first (second) period to the second (first) period to maximize its profit. This effect is given by $\partial \hat{p}_{r,2}/\partial R_1 \cdot \hat{R}_1' \cdot d\hat{p}_{r,1}/dI$, where $\hat{R}_1'$ denotes $\partial \hat{R}_1/\partial p_{r,1}$. Contrary to the direct price effect, the supply-shifting effect changes the resource prices in both the first and second periods.

We obtain from (4) that

$$\frac{d^2 \hat{\Pi}_f}{dI dp_{r,1}} = -\delta C''_{f,2} \frac{d\tilde{R}_2}{dI} R_1', \tag{6}$$

where

$$\frac{d\tilde{R}_2}{dI} = \frac{\partial \hat{R}_2}{\partial p_{r,2}} \frac{\partial \hat{p}_{r,2}}{\partial I} - \frac{\partial \hat{M}_h}{\partial I}. \tag{7}$$

$d\tilde{R}/dI$ denotes the effect of a change in the investment by Firm h on the demand for the resource supplied by Firm f given the resource supply in the first period (R_1). Thus, the supply-shifting effect can be rewritten as

$$\frac{\partial \hat{p}_{r,2}}{\partial R_1} \cdot \hat{R}_1' \cdot \frac{d\hat{p}_{r,1}}{dI} = \frac{\partial \hat{p}_{r,2}}{\partial R_1} \cdot \hat{R}_1' \cdot \frac{\delta C''_{f,2} \hat{R}_1' \frac{d\tilde{R}_2}{dI}}{\frac{d^2 \hat{\Pi}_f}{dp_{r,1}^2}}. \tag{8}$$

From (2), we obtain:

$$\frac{\partial^2 \hat{\pi}_{f,2}}{\partial R_1 \partial p_{r,2}} = -C''_{f,2}\frac{\partial \hat{R}_2}{\partial p_{r,2}} > 0. \tag{9}$$

Because $\partial \hat{R}_2/\partial p_{r,2} < 0$, $\partial \hat{p}_{r,2}/\partial R_1 > 0$ holds. Moreover, $\hat{R}'_1 < 0$ and $C''_{f,2} > 0$ hold. Thus, the supply-shifting effect depends on the sign of $d\tilde{R}_2/dI$.

Lemma 2

If $d\tilde{R}_2/dI < 0$ (resp. $d\tilde{R}_2/dI > 0$), an increase in the investment in new mines by Firm h decreases (resp. increases) the resource price in the first period, and increases (resp. decreases) the resource price in the second period through the supply-shifting effect.

When the direct price effect is negative ($\partial \hat{p}_{r,2}/\partial I < 0$), $d\tilde{R}_2/dI$ can be either negative or positive. Because $\partial \hat{R}_2/\partial p_{r,2} < 0$, the price decrease in the second period increases the demand for the resource extracted by Firm f given the amount of extraction of Firm h (the first term in (7)). On the other hand, an increase in investment by Firm h increases the resource supply of Firm h given the resource price, which means that the demand for the resource extracted by Firm f decreases (the second term in (7)). Thus, $d\tilde{R}_2/dI$ is either positive or negative. However, when the direct effect is positive ($\partial \hat{p}_{r,2}/\partial I > 0$), both terms work to decrease the demand for the resource extracted by Firm f. In this case, $d\tilde{R}_2/dI$ is necessarily negative.

From (3) and (5), it is obtained that

$$\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{p}_{r,2}}{\partial I} = \frac{\frac{\partial \hat{R}_2}{\partial p_{r,2}} - C''_{f,2}\left(\frac{\partial \hat{R}_2}{\partial p_{r,2}}\right)^2 + (\hat{p}_{r,2} - C'_{f,2})\frac{\partial^2 \hat{M}_h}{\partial I \partial p_{r,2}}\frac{\partial \hat{R}_2}{\partial p_{r,2}}/\frac{\partial \hat{M}_h}{\partial I}}{2\frac{\partial \hat{R}_2}{\partial p_{r,2}} - C''_{f,2}\left(\frac{\partial \hat{R}_2}{\partial p_{r,2}}\right)^2 + (p_{r,2} - C'_{f,2})\cdot\frac{\partial^2 \hat{R}_2}{\partial p^2_{r,2}}} \cdot \frac{\partial \hat{M}_h}{\partial I}.$$

Thus, recalling that $\partial \hat{R}_2/\partial p_{r,2} < 0$, the more highly the demand for the resource supplied by Firm f is convex ($\partial^2 \hat{R}_2/\partial p^2_{r,2} > 0$), the more likely it is that $d\tilde{R}_2/dI > 0$ hold (see (7)). It should be noted that even if the demand curve for final goods is concave, the demand for the resource supplied by Firm f can be convex because $\hat{R}_2 = \hat{X}_2 - \hat{M}_h$. Moreover, even if $\partial^2 \hat{R}_2/\partial p^2_{r,2} < 0$, $d\tilde{R}_2/dI > 0$ may hold.

From Lemmas 1 and 2, we obtain the effects of a change in the investment in the exploration/acquisition of new mines by Firm h on the resource prices in both periods. Depending on the direction and the size of both the direct price and the supply-shifting effects, there are four possible cases.

First, when $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$ and $d\tilde{R}_2/dI > 0$, both the direct price and the supply-shifting effects decrease the resource price in the second period, and the latter increases it in the first period.

Proposition 1

Suppose that $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$ and $d\tilde{R}_2/dI > 0$ hold. Then, an increase in the mines owned by Firm h increases the resource price in the first period, and decreases it in the second period.

It is interesting to consider the policy implication of this result. Suppose that the support by the home government for the investment by Firm h increases the amount of investment. In such a case, the government's support may induce an increase in the present resource price.

Next, when $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$ and $d\tilde{R}_2/dI < 0$, the direct price effect decreases the resource price in the second period, while the supply-shifting effect increases (resp. decreases) the resource price in the second (resp. first) period. As far as the resource price in the second period, both effects conflict with each other. Thus, depending on the sizes of both effects, there are two possible cases. Recalling that $\hat{R}_1 = \hat{X}(\hat{p}_{r,1})$, we establish the following result.

Proposition 2

Suppose that $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$ and $d\tilde{R}_2/dI < 0$ holds. If the demand curve for final goods is concave ($\hat{R}_1'' < 0$), an increase in the mines owned by Firm h necessarily decreases the resource prices both in the first and second periods. On the other hand, if the demand curve for final goods is convex ($R_1'' > 0$), an increase in the mines owned by Firm h may increase the resource price in the second period.

See Appendix A for the proof.

The intuition is as follows. When $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$, an investment in the exploration of new mines by Firm h makes the demand for the resource extracted by Firm f more elastic. Thus, in terms of the direct price effect, Firm f has an incentive to decrease the resource price in the second period, and accordingly, increase the supply in the second period. However, as noted above, the supply-shifting effect is assumed to work to increase the resource price in the second period. Then, which effect dominates the other depends on the shape of the demand curve for final goods. When the demand curve for final goods is concave, $\partial p_{r,1}/\partial R_1$ becomes greater as the supply in the first period increases. On the other hand, when the demand curve for final goods is convex, $\partial p_{r,1}/\partial R_1$ becomes smaller as the supply in the first period increases. Therefore, Firm f has less incentive to shift the resource supply from the second to the first periods when the demand curve for final goods is concave than when it is convex. Consequently, when the demand curve is concave, the direct price effect necessarily dominates the supply-shifting effect, whereas when the demand curve is convex, the supply-shifting effect may dominate the direct price effect.

Let us now turn to the case where $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} < 0$ holds. This case is possible when considering investments in resources. For example, consider the exploration of oil fields in a certain area. The resource extraction increases given the resource price as the number of pits/platforms increases by investments. However, because the oil reserve in a certain area is finite, an additional pit/platform gives rise to negative externalities in the extraction of existing pits/platforms in the same area. In such a case, the marginal cost of extraction rapidly increases when the stock becomes small. Thus, an additional investment may decrease the marginal increase of extraction in response to an increase in the resource price. This type of shift of a supply curve is depicted in Figure 4. In this case, it follows from (5) that a decrease in the resource price in the second period is smaller when $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} < 0$ than when $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$. An increase in the investment may even increase the resource price in the second period. This is because the demand for the resource supplied by Firm f becomes less elastic. In particular, from (7) and (8), we obtain the following proposition.

Proposition 3

If the direct price effect is positive ($\partial \hat{p}_{r,2}/\partial I > 0$), an increase in the mines owned by Firm h necessarily increases the resource price in the second period, and decreases it in the first period.

Both the direct price and supply-shifting effects work in the same direction with respect to the price in the second period. The resource supply by Firm f in the second period decreases, while that in the first period increases.

One point should be emphasized. The result obtained in the case of $\partial^2 \hat{M}_h / \partial I \partial p_{r,2} < 0$ is specific to the effect of an investment in resource exploration. It follows from (5) that the necessary condition for $\partial \hat{p}_{r,2} / \partial I > 0$ to hold is $\partial^2 \hat{M}_h / \partial I \partial p_{r,2} < 0$. And, this inequality is specific to the shift of a resource supply curve as a result of investment in exploration.

Having examined the effects of an increase in mines owned by Firm h on the resource prices, we obtain important policy implications. The support by the government of a resource-importing country does not necessarily have an effect on the resource price as intended, if the government aims to lower the resource price. In some cases, the support leads to an increase in the present resource price, and in other cases it may lead to an increase in the future resource price.

The comparison between our results and those obtained under a continuous infinite-horizon model (Gilbert and Goldman (1978)) is interesting. In a continuous infinite-horizon model, demand and supply structures are simplified. And, it is obtained that an increase in the possibility of entry of competitive suppliers gives a monopolist an incentive to decrease the present extraction. This behavior leads to delays in the depletion of the stock owned by the monopolist and accordingly delays the entry. Observing the changes in prices, Proposition 1 seems to produce a similar result. However, the reasons for the price increase in the present period(s) are different. In Gilbert and Goldman (1978), by the increase in the present price, the entry in a certain future period is less attractive for a potential entrant. In contrast, in our analysis, the timing and the scale of entry is predetermined when the monopolist chooses the present resource price. Depending on the demand and supply structure, the monopolist may shift the supply from the present period(s) to the future period(s). When considering the case where Firm h determines the investment amount in the second period, we obtain a similar effect as Gilbert and Goldman (1978) (see Subsection 6.3).

5 Welfare

Having examined the price effects, we now investigate the welfare effect of an increase in mines owned by Firm h: the sum of the consumer surplus and the profit of firms. In this section, we assume the constant elasticity of the slope of the inverse demand curve for final goods.

Assumption 2

$-P_x''X/P_x' = \epsilon = const.$

When the inverse demand curve is concave (resp. convex), ϵ is negative (resp. positive).

The effect of a change in the investment amount on each factor of welfare is as follows. First, the consumer surplus of country i in period j ($j = 1, 2$) is defined as: $CS_{i,j} = \beta_i \int_0^{X_j} P_{x,j}(z)dz (j = 1, 2)$, where β_i denotes the ratio of the market scale of country i to the scale of the whole world market. Differentiating the consumer surplus in period j with respect to I yields:

$$\frac{dCS_{i,j}}{dI} = \beta_h \hat{p}_{r,j} \frac{d\hat{X}_j}{dp_{r,j}} \frac{d\hat{p}_{r,j}}{dI} = \beta_h \hat{p}_{r,j} \frac{n}{\hat{P}'_{x,j}(n+1-\epsilon)} \frac{d\hat{p}_{r,j}}{dI}. \tag{10}$$

It is clear that, the lower the resource price, accordingly, the lower is the price of the final good, and the greater is the consumer surplus.

Second, the effect of a change in the investment amount on the profit of each final goods producer from the supply of final goods is given by

$$\frac{d\hat{\pi}_{i,j}^{FG}}{dI} = \frac{\epsilon - 2}{n+1-\epsilon} \cdot \hat{x}_j \cdot \frac{d\hat{p}_{r,j}}{dI}, \quad j = 1, 2, \tag{11}$$

where superscript FG denotes the profit from the supply of final goods. Except for $\hat{\pi}_{h,2}$, $\hat{\pi}_{i,j}^{FG} = \hat{\pi}_{i,j}$ holds. This derivative states that, when $\epsilon < 2$ (resp. $\epsilon > 2$), a decrease (resp. an increase) in the resource price increases the profit of firm i from the supply of final goods.

Third, using the envelope theorem, the effect on the profit from extraction of Firm h in the second period is given by

$$\frac{d\hat{\pi}_{h,2}^{M}}{dI} = \hat{M}_h \frac{d\hat{p}_{r,2}}{dI} - \frac{\partial C_h}{\partial I}, \tag{12}$$

where superscript M denotes the profit from the extraction. Because $\partial C_h/\partial I < 0$, if $d\hat{p}_{r,2}/dI > 0$, $d\hat{\pi}_{h,2}^{M}/dI$ is necessarily positive. From (11) and (12), even if $d\hat{p}_{r,2}/dI < 0$, when $\epsilon < 2$, $d(\hat{\pi}_{h,2}^{FG} + \hat{\pi}_{h,2}^{M})/dI$ may be positive. In particular, it is likely to hold when the demand of Firm h for the resource is greater than its own supply/extraction.

We can also consider the total profit of Firm h, which is given by

$$\Pi_h = \pi_{h,1} - C_I(I, s) + \delta\pi_{h,2},$$

where C_I denotes the investment cost. It is assumed that $\partial C_I/\partial I > 0$. Therefore, the effect of a change in the investment on the total profit of Firm h is ambiguous. The effect on the profit of Firm f is given by

$$\frac{d\hat{\Pi}_f}{dI} = -\delta(\hat{p}_{r,2} - C'_{r,2})\frac{\partial \hat{M}_h}{\partial I} < 0. \tag{13}$$

Now let us consider home welfare. The effect of an increase in mine investment by Firm h on home welfare depends on whether the investment amount is optimal in terms of the profits of Firm h in the case of no support from the government. In the real world, there are risks of failing in the acquisition of new mines. In such a case, without government support, the investment amount is likely to be smaller than the optimum in terms of the profits of Firm h, which implies that $d\Pi_h/dI > 0$. In this case, if $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$, $\epsilon < 0$, and $d\tilde{R}/dI < 0$ hold, the home government's support encourages Firm h to invest in exploration and improves home welfare. This is because the resource prices in both periods decrease when these conditions are satisfied and, accordingly, the consumer surplus necessarily increases in both periods (see Proposition 2). This implies that when the firm's investment is insufficient because of risks, the government's support can achieve its goal: the procurement of resources at low prices and the improvement of welfare.

We should note that even if the investment by Firm h is insufficient in terms of the total profit of Firm h in the case of no government's support, it is possible that the support could deteriorate home welfare. When the resource price increases either in the first or second period, the consumer surplus in that period decreases. Therefore, home welfare may be reduced in that period. Consequently, depending on the time preference of consumers, total home welfare may decrease in response to an increase in investment by Firm h.

What is the effect on other resource-importing countries? Because other final goods producers are assumed not to invest in exploration, if $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$, $\epsilon < 0$, and $d\tilde{R}/dI < 0$ hold, an increase in the investment amount by Firm h improves the welfare of other resource-importing countries. In this case, the investment is likely to be insufficient in terms of the total welfare of resource-importing countries because the home government does not take into consideration the positive effect on welfare of other countries. On the other hand, in other cases, other resource-importing countries may lose from the investment by Firm h through an increase in the resource price, because the consumer surplus in those countries decreases. In such a case, the investment in exploration by a final goods producer may be excessive in terms of the maximization of the total welfare of resource-importing countries.

Finally, we examine the welfare of the resource-exporting country. It follows from (13) that an increase in the investment of a final goods producer always works against the profit of Firm f. However, if the market scale of the foreign country is large, consumers benefit from the decrease in the price of final goods. Thus, the effect on the resource-exporting country depends on its relative market scale.

6 Extensions

In this section, we investigate three extended situations: joint exploration, entry of speculators, and the case in which Firm h chooses the investment amount after Firm f chooses the resource price in the second period (the non-commitment case).

6.1 Joint Exploration

We have so far assumed that Firm h receives all of the gains from exploration. This assumption fits for the case in which undeveloped deposits exist in the jurisdiction of the home country. In general, however, many types of resources are unevenly distributed across a small number of countries in the real world. Firm h may have to purchase the right of exploration/extraction for a mine located outside of the jurisdiction of the home country. In such a case, it is likely that the resource-exporting country will receive a part of the gains from extraction.

In this subsection, we consider a case in which the following conditions hold: (a) all deposits are owned by Firm f, (b) some of them have not been developed, and (c) Firm f and Firm h jointly embark on the development of a new mine.[15] Then, they share the profit from extracting resources from the new mine. In such a case, Firm f chooses the

[15]If Firm h has some advanced technologies, Firm f may have an incentive to embark on joint exploration.

resource prices in both periods to maximize its profit, which includes a part of the joint profit:

$$\Pi_f^J = \Pi_f + \delta\theta(p_{r,2}M_h - C_h(M_h, I)),$$

where θ is the share of Firm f, and superscript J denotes the case of joint exploration. In this case, the FOC ((2)) can be rewritten as

$$\frac{\partial \pi_{f,2}}{\partial p_{r,2}} = R_2 + (p_{r,2} - C'_{f,2}) \cdot \frac{\partial R_2}{\partial p_{r,2}} + \theta \hat{M}_h = 0. \tag{14}$$

Accordingly, (5) can be rewritten as

$$\frac{\partial^2 \hat{\pi}_{f,2}}{\partial I \partial p_{r,2}} = -(1-\theta)\frac{\partial \hat{M}_h}{\partial I} + C''_{f,2}\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{M}_h}{\partial I} - (\hat{p}_{r,2} - C'_{f,2})\frac{\partial^2 \hat{M}_h}{\partial I \partial p_{r,2}}. \tag{15}$$

Because $\partial \hat{M}_h/\partial I > 0$, we obtain that, given the resource price in the first period, Firm f has less incentive to decrease the resource price in the second period in response to an increase in the investment by Firm h when exploration is a joint project than when Firm h explores by itself. In other words, the higher the share of Firm f in the profit of a new mine, the less likely it is that the resource price in the second period decreases. It can also be said that if $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} < 0$, the direct price effect is more likely to be positive when exploration is a joint project than when Firm h does the exploration itself.

Moreover, if both the direct price and supply-shifting effects conflict with each other with respect to the resource price in the second period, it is more likely that the latter effect dominates the former when exploration is a joint project than when Firm h explores by itself (See Appendix B for the detail). Thus, we obtain the following proposition.

Proposition 4

It is more likely that an increase in the mines owned by Firm h increases the resource price in the second period when the home government increases support for the joint project than when it increases the support for independent exploration.

6.2 Entry of Speculators

We have so far implicitly assumed that Firm f can choose the resource prices in both periods. However, speculators may be able to enter the resource market. In particular, when the demand curve for final goods is convex, it is possible that the rate of an increase in the optimal price for Firm f is greater than the interest rate. Accordingly, if speculators can enter the resource market without any entry costs, $p_{r,2} = p_{r,2}/\delta$ holds. In this case, the objective of Firm f is to maximize Π_f subject to $p_{r,2} = p_{r,1}/\delta$. In other words, Firm f cannot choose the resource price in the second period independent of that in the first period. Then, the FOC is given by

$$\begin{aligned} \frac{d\Pi_f}{dp_{r,1}} &= R_{D,1} + \left\{p_{r,1} - (1-\delta)C'_{f,1} - \delta C'_{f,2}\right\} \cdot \frac{\partial R_{D,1}}{\partial p_{r,1}} \\ &\quad + \delta \cdot \left(\frac{R_2}{\delta} + \frac{p_{r,2} - C'_{f,2}}{\delta} \cdot \frac{\partial R_2}{\partial p_{r,2}} \right) = 0. \end{aligned} \tag{16}$$

We also assume that the SOC holds. Then, it follows from (16) that

$$\frac{d^2\Pi_f}{dIdp_{r,1}} = -\delta C''_{f,2}\frac{d\hat{R}_2}{dI}R'_1 - \frac{\partial \hat{M}_h}{\partial I} + C''_{f,2}\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{M}_h}{\partial I} - (\hat{p}^S_{r,2} - C'_{f,2})\frac{\partial^2 \hat{M}_h}{\partial I \partial p_{r,2}}. \tag{17}$$

Note that this is the case when Firm h explores the new mines itself ($\theta = 0$).

It seems to be the same as the case when Firm f can choose the resource price in each period. However, in the present situation, $d\tilde{R}_2/dI = -d\hat{M}_h/dI < 0$, which is different from (7), because Firm f cannot choose the resource price in the second period independent of that in the first period. Thus, if $\partial^2\hat{M}_h/\partial I \partial p_{r,2} > 0$ holds, (17) is necessarily negative.

Proposition 5

When speculators enter the resource market, if $\partial^2\hat{M}_h/\partial I \partial p_{r,2} > 0$ holds, an increase in mines owned by Firm h necessarily decreases the resource prices in both periods.

In this case, the possibility of entry of speculators can prevent the resource price from increasing as a result of the strategic behavior of Firm f in response to an increase in the exploration of Firm h.

However, as noted in the previous section, it is possible that $\partial^2\hat{M}_h/\partial I \partial p_{r,2} < 0$ holds. In such a case, the last term in (17) results in the resource price increasing in both periods. In particular, this is likely to take place when $C''_{f,2}$ is small. Moreover, it follows from the analysis in the previous subsection that joint exploration increases this possibility.

6.3 The Non-commitment Case

It is possible to consider a situation in which Firm f chooses resource prices before Firm h determines its investment amount, if we consider a long-term horizon. We refer to this case as the non-commitment case. In particular, the structure of the game in the second period is assumed to be as follows: First, Firm f determines the resource price; second, Firm h chooses the amount of investment in exploration/acquisition; and third, Firm h chooses the amounts of extraction; and fourth, final goods producers choose the amounts of their own outputs.

The profit functions in the non-commitment case are given by

$$\pi_{h,2} = (p_{x,2} - p_{r,2}) \cdot x_{i,2} + p_{r,2} M_h - C_h(M_h, I) - C_I(I, s),$$

$$\pi_{h,1} = (p_{x,1} - p_{r,1}) \cdot x_{i,1}.$$

It is assumed that $\partial C_I/\partial I > 0$, $\partial C_I/\partial s < 0$, $\partial^2 C_I/\partial I^2 > 0$, $\partial^2 C_I/\partial s \partial I < 0$. The third and fourth steps are the same as the former case (Section 3), and we obtain the equilibrium outputs and the amount of extraction by Firm h given I and $p_{r,2}$.

Firm h chooses the amount of exploration given the resource price offered by Firm f. Using the envelope theorem, the FOC is given by:

$$\frac{d\pi_{h,2}}{dI} = -\frac{\partial C_h}{\partial I} - \frac{\partial C_I}{\partial I} = 0. \tag{18}$$

The SOC is assumed to hold:

$$\frac{d^2\pi_{h,2}}{dI^2} = -\frac{\partial^2 C_h}{\partial I^2} - \frac{\partial^2 C_h}{\partial I \partial M_h}\frac{\partial M_h}{\partial I} - \frac{\partial^2 C_I}{\partial I^2} < 0.$$

Thus, we obtain the equilibrium amount of exploration: $\hat{I}(p_{r,2})$. Moreover, we obtain that

$$\frac{d^2\pi_{h,2}}{dI dp_{r,2}} = -\frac{\partial^2 C_h}{\partial I \partial M_h}\frac{\partial M_h}{\partial p_{r,2}} > 0.$$

Thus, $d\hat{I}/dp_{r,2} > 0$ holds.

Taking into consideration the effect of a change in the resource price on the exploration amount and outputs, Firm f chooses the resource price for the second period. The demand for the resource extracted by Firm f is given by: $R_{D,2}(p_{r,2}, I) = \hat{X}_2(p_{r,2}) - \hat{M}_h(p_{r,2}, I)$, and the FOC is

$$\frac{\partial \pi_{f,2}}{\partial p_{r,2}} = R_2 + (p_{r,2} - C'_{r,2}) \cdot \left(\frac{\partial R_2}{\partial p_{r,2}} - \frac{\partial M_h}{\partial I}\frac{dI}{dp_{r,2}} \right) = 0. \tag{19}$$

We also assume that the SOC is satisfied.[16] Thus, we obtain the equilibrium resource price and the supply of the resource by Firm f in the second period: $\hat{p}_{r,2}(R_1)$, $\hat{R}_2 = R_{D,2}(\hat{p}_{r,2}, \hat{I})$.

Note that the situation in the first period is the same as that in the former case (see Subsection 3.2): i.e., Firm f chooses the resource price first, and final goods producers chooses their own output quantities. Therefore, the FOCs for the final goods producers and Firm h are also the same as those in the former case.

It follows from (18) that $d^2\pi_{h,2}/dIds > 0$. Thus, given the resource price in the second period, an increase in support by the home government increases the exploration of mines by Firm h. On the other hand, the effect of an increase in the support on the resource price is ambiguous. From (4) and (19), it is obtained that:

$$\begin{aligned}\frac{\partial^2 \pi_{f,2}}{\partial p_{r,2}\partial s} &= -\frac{\partial M_h}{\partial I}\frac{\partial I}{\partial s}\cdot\left\{-1 + C''_{f,2}\left(\frac{\partial \hat{R}_2}{\partial p_{r,2}} - \frac{\partial \hat{M}_h}{\partial I}\frac{\partial I}{\partial p_{r,2}}\right)\right\} \\ &\quad - (p_{r,2} - C'_{r,2})\cdot\left(\frac{\partial^2 \hat{M}_h}{\partial p_{r,2}\partial I}\frac{\partial I}{\partial s} + \frac{\partial^2 \hat{M}_h}{\partial I^2}\frac{\partial I}{\partial s}\frac{\partial I}{\partial p_{r,2}} + \frac{\partial \hat{M}_h}{\partial I}\frac{\partial^2 I}{\partial p_{r,2}\partial s}\right), \quad (20)\end{aligned}$$

$$\frac{d^2\Pi_{f,1}}{\partial p_{r,1}\partial s} = -\delta R'_1 C''_{r,2}\left\{\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial p_{r,2}}{\partial s} - \frac{\partial M_h}{\partial I}\left(\frac{\partial I}{\partial p_{r,2}}\frac{\partial p_{r,2}}{\partial s} + \frac{\partial I}{\partial s}\right)\right\}. \quad (21)$$

In (20), only the second term in the parentheses in the second line increases the resource price in response to an increase in the government's support. However, all of the other terms decrease the resource price. Therefore, in general, it is likely that the support by the home government for the exploration of Firm h lowers the resource price in the second period given the resource price in the first period.

When focusing on (21), we find an additional term as compared with (6): $\partial I/\partial p_{r,2} \cdot \partial p_{r,2}/\partial s$. This term is negative if $\partial p_{r,2}/\partial s < 0$. In such a case, it gives Firm f an incentive to increase the resource price in the first period in response to an increase in the support of the home government for Firm h. The reason is that Firm f can discourage the investment in exploration by Firm h by increasing the resource price in the first period, which means that the extraction cost of Firm f in the second period becomes lower and

[16] Precisely, the SOC is given by:

$$\frac{\partial^2 \pi_{f,2}}{\partial p_{r,2}^2} = 2\frac{\partial R_{D,2}}{\partial p_{r,2}} - C''_{r,2}\left(\frac{\partial R_{D,2}}{\partial p_{r,2}}\right)^2 + (p_{r,2} - C'_{r,2})\cdot\left(\frac{\partial^2 R_{D,2}}{\partial p_{r,2}^2} - \frac{\partial^2 M_h}{\partial p_{r,2}\partial I}\frac{dI}{dp_{r,2}} - \frac{\partial M_h}{\partial I}\frac{d^2 I}{dp_{r,2}^2}\right) < 0.$$

the marginal benefit of investment of Firm h becomes smaller.

In total, it is more likely in the non-commitment case that the resource price in the first period increases than in the former case in Section 4.

7 Conclusion

Assuming a simple two-period model, we examine the effects of the acquisition of mines by a home final goods producer on the resource prices in both the first period (the present period) and the second period (the future period), profits of firms, and welfare. We also consider three extended situations: joint exploration, the existence of speculators, and the non-committed investment.

We find that an increase in the mines owned by the home firm can increase the resource price in the first period and/or, interestingly, that in the second period. This implies that the total resource consumption in the first or second period may decrease. The strategic behavior of a resource extracting firm located in a resource-exporting country produces this result. Whether or not the resource price increases in either period depends on the demand structure for final goods and the supply condition of the resource by the home firm in the second period. Moreover, we obtain the following results from the analysis on extended situations. First, when the home firm and the resource-extracting firm embark on joint exploration, it is more likely that the resource price in the second period will increase in response to an increase in mines owned by the home firm. Second, when speculators enter the market, the resource prices in both periods change in the same direction. Even in such a case, under certain conditions, they can increase in response to the acquisition of new mines by the home firm. Third, it is more likely in the non-commitment case that the resource price in the first period increases than in the case in which Firm h determines the investment amount before the first period begins.

We did not consider three interesting points specific to this kind of resource issue. First, there is often uncertainty surrounding the result of investments in new mines. There is also uncertainty regarding the future demand for final goods/resources and, accordingly, resource prices. These uncertainties can influence the behavior of firms. Second, the governments of resource-exporting countries also behave strategically in the real world.

For example, they sometimes restrict the export of resources, or levy taxes on exploitation. Alternatively, they may set the price menu of a mine so that they acquire all of the gains that accrue to the home country. In such a case, the home government's support merely benefits the foreign country. Third, we did not consider a scenario in which the resource-extracting firm sets different prices for different final goods producers. In the real world, a resource-extracting firm negotiates for the selling price with each final goods producer. Thus, a final goods producer may gain another benefit from an investment in exploration: it may be able to purchase resources from the resource-extracting firm at a lower price than other final goods producers do. These factors also affect the firms' behavior and the resource market. The investigation of these points is ripe for future research.

Appendix A: Proof for Proposition 2

From (4), $d^2\Pi_f/dp_{r,1}^2$ is written as follows:

$$\frac{d^2\Pi_f}{dp_{r,1}^2} = (2-(1-\delta)C''_{f,1}\hat{R}'_1)\hat{R}'_1+(p_{r,1}-(1-\delta)C'_{f,1}-\delta C'_{f,2})\hat{R}''_1-\delta C''_{f,2}\hat{R}'^2_1(1+\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{p}_{r,2}}{\partial R_1}). \quad (22)$$

Moreover, from (7), the supply-shifting effect ((8)) can be rewritten as

$$\frac{\partial \hat{p}_{r,2}}{\partial I} \cdot \frac{\delta C''_{f,2}\hat{R}'^2_1}{\Lambda} \cdot \left(\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{p}_{r,2}}{\partial R_1} - \frac{\partial \hat{M}_h/\partial I \cdot \partial \hat{p}_{r,2}/\partial R_1}{\partial \hat{p}_{r,2}/\partial I} \right). \quad (23)$$

From (5) and (9), we obtain that

$$-\frac{\partial \hat{M}_h/\partial I \cdot \partial \hat{p}_{r,2}/\partial R_1}{\partial \hat{p}_{r,2}/\partial I} = \frac{C''_{f,2}\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{M}_h}{\partial I}}{-\frac{\partial \hat{M}_h}{\partial I} + C''_{f,2}\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{M}_h}{\partial I} - (\hat{p}_{r,2} - C'_{f,2})\frac{\partial^2 \hat{M}_h}{\partial I \partial p_{r,2}}}. \quad (24)$$

Thus, because $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$ is assumed, it holds that

$$0 < -\frac{\partial \hat{M}_h/\partial I \cdot \partial \hat{p}_{r,2}/\partial R_1}{\partial \hat{p}_{r,2}/\partial I} < 1.$$

If $d\hat{R}_2/dI < 0$, it holds that

$$0 < \frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{p}_{r,2}}{\partial R_1} - \frac{\partial \hat{M}_h/\partial I \cdot \partial \hat{p}_{r,2}/\partial R_1}{\partial \hat{p}_{r,2}/\partial I} < 1 + \frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{p}_{r,2}}{\partial R_1}. \quad (25)$$

Equations from (22) through (25) state that the absolute value of (23) is smaller than that of the direct price effect ($\partial \hat{p}_{r,2}/\partial I$), if $R''_1 < 0$, $\partial^2 \hat{M}_h/\partial I \partial p_{r,2} > 0$, and $d\hat{R}_2/dI < 0$ hold.

On the other hand, if $R''_1 > 0$,

$$\frac{\delta C''_{f,2}\hat{R}'^2_1}{\Lambda} \cdot \left(\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{p}_{r,2}}{\partial R_1} - \frac{\partial \hat{M}_h/\partial I \cdot \partial \hat{p}_{r,2}/\partial R_1}{\partial \hat{p}_{r,2}/\partial I} \right)$$

may be greater than one. Thus, the supply-shifting effect may dominate the direct price effect.

Appendix B: The supply-shifting Effect in the Case of Joint Exploration

In the case of joint exploration, (24) can be rewritten as:

$$-\frac{\partial \hat{M}_h/\partial I \cdot \partial \hat{p}_{r,2}/\partial R_1}{\partial \hat{p}_{r,2}/\partial I} = \frac{C''_{f,2}\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{M}_h}{\partial I}}{-(1-\theta)\frac{\partial \hat{M}_h}{\partial I} + C''_{f,2}\frac{\partial \hat{R}_2}{\partial p_{r,2}}\frac{\partial \hat{M}_h}{\partial I} - (\hat{p}_{r,2} - C'_{f,2})\frac{\partial^2 \hat{M}_h}{\partial I \partial p_{r,2}}}. \tag{26}$$

It is likely that the denominator of (26) becomes smaller as θ increases, which implies that the supply-shifting effect is likely to become greater as θ increases.

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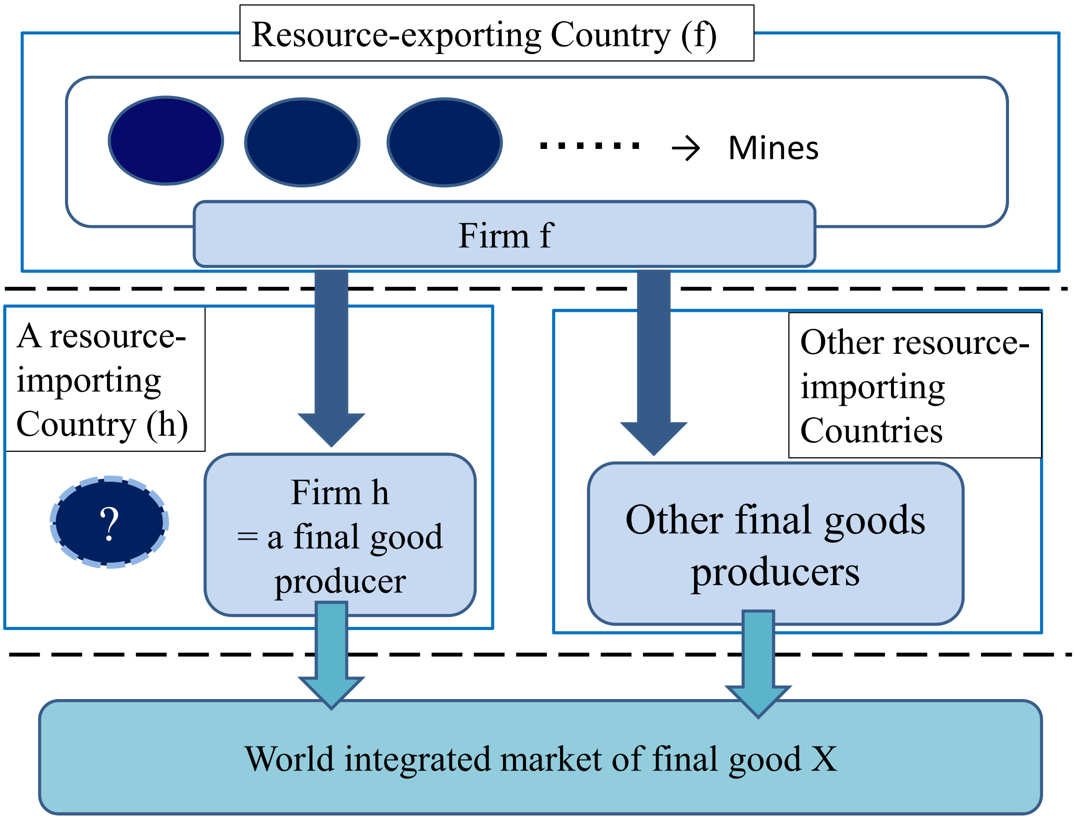

Figure 1. The structure of the model.

1st period

The home government subsidizes the investment in exploration of mines by Firm h. (Exogenous)
→ Firm h determines the investment amount. (Exogenous)

Firm f chooses the resource price in the first period.

↓

Final goods producers choose their own outputs (and the amounts of resource inputs)

↓

2nd period

Firm f chooses the resource price in the first period.

↓

Firm h chooses the extraction amount.

↓

Final goods producers choose their own outputs (and the amounts of resource inputs)

Figure 2. The structure of the game.

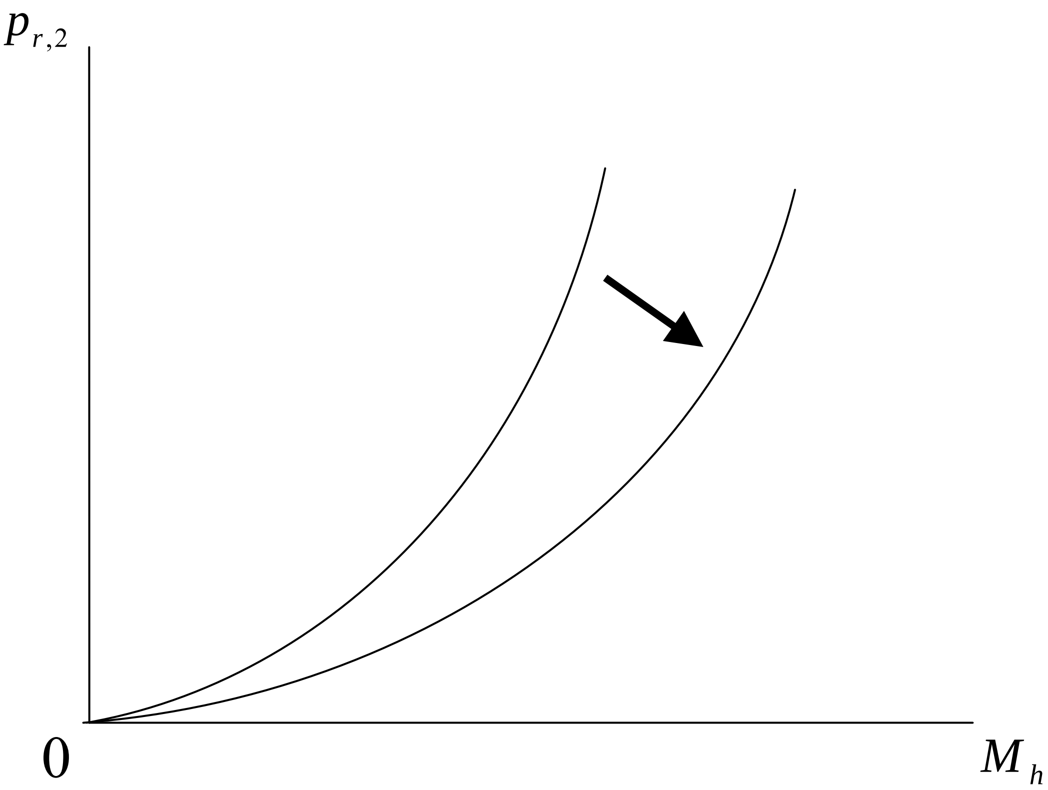

Fig.3. The shift of the supply curve by Firm h when $\partial\hat{M}_h \big/ \partial I \partial p_{r,2} > 0$

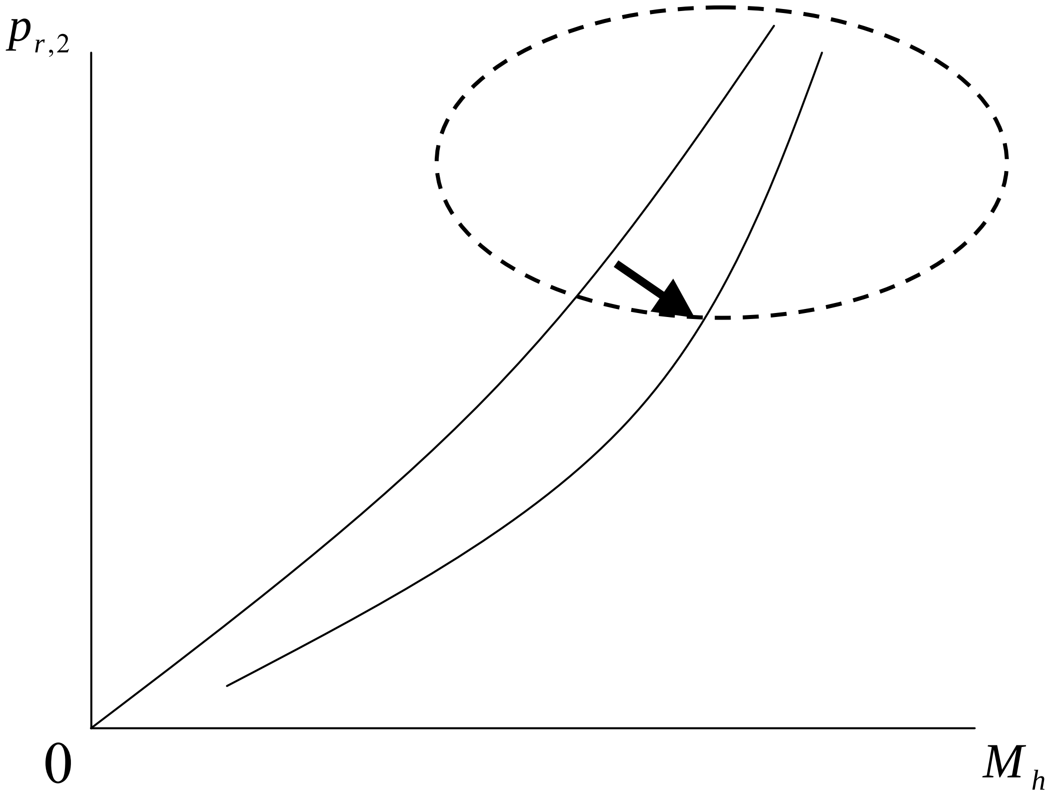

Fig.4. The shift of the supply curve by Firm h when $\partial\hat{M}_h \big/ \partial I \partial p_{r,2} < 0$