Optimal Tariffs on Exhaustible Resources in the Presence of Cartel Behavior

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Abstract

We present a model of bilateral monopoly between resource-importing countries and a resource-exporting country. We show that there exists a threshold level of marginal cost beyond which the resource-importing coalition would prefer bilateral monopoly to free trade. In the case of two non-collusive asymmetric importing countries, we show that asymmetry of market sizes also plays a role in determining the welfare gains under free trade or tariff war. As importing countries become more asymmetric, their aggregate welfare is more likely to be higher under the tariff war.

JEL Classifications: F12, F21, F23

Keywords: tariff war, natural resources, bilateral monopoly, dynamic game

1. Introduction

This paper analyses a dynamic game involving resource-importing countries and resource-exporting countries. Our first objective is to compare the time path of extraction under bilateral monopoly with that under free trade. For each group of countries, we also compare its welfare level under free trade and that under bilateral monopoly. We next consider the case where the importing countries do not form a coalition, and analyze a dynamic Nash equilibrium involving three players: a resource exporting country and two asymmetric importing countries.

It is well known that world welfare is maximized under free trade. An interesting question is whether there exist parameter values such that one of the two groups of countries is better off under bilateral monopoly than under free trade. In our model, it turns out that there is a threshold level of the marginal extraction cost parameter beyond which the resource-importing coalition would prefer bilateral monopoly to free trade.

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The higher the rate of discount, the greater the corresponding threshold marginal cost level.

A related question is the division of gains from trade (whether under free trade, or in a tariff-ridden bilateral monopoly) between the two groups of countries. Under free trade, the resource-exporting coalition's share of gains from trade is a function of the cost parameter and the discount rate. Under bilateral monopoly, we show that in the special case where the inverse demand functions of resource-importing countries have a common intercept, two thirds of the gains from trade accrue to the coalition of resource-exporting countries, regardless of the values of the marginal cost parameter and the discount rate. In the case of two non-collusive asymmetric importing countries, we show that the asymmetry of market sizes also plays a role in determining the welfare gains under free trade or tariff war. As the two importing countries become more asymmetric in terms of their relative size, their aggregate gain from trade is more likely to be higher under tariff war than under free trade. This seems to be consistent with the static theory of non-collusive duopoly: if the duopolists become more asymmetric in terms of costs, the industry profit will be higher (as one firm becomes almost a monopolist).

We begin by characterizing a world competitive equilibrium in which an exhaustible resource is extracted and traded. We then contrast this competitive scenario with the bilateral monopoly (or trade-war) scenario, in which the resource-exporting nations, acting as a cartel, take over the private deposits and become the sole supplier of the extracted resource, exploiting its monopoly power, while the coalition of resource-importing countries imposes a tariff on the imported resource in order to take advantage of its monopoly power. We compare the extraction paths, the price paths, and the welfare level of each group of countries under the two scenarios.

We next consider the case where the resource-importing countries do not cooperate with each other. They each set their own tariff rate on the imported natural resources. We compare the outcome of this scenario with the outcomes under free trade and under bilateral monopoly. Of particular interest is the situation where the non-cooperative importing countries are not identical in size. In the case of two asymmetric importing countries, we show that, given the total market size, greater asymmetry implies greater aggregate welfare gain for the importing countries, and a smaller welfare level for the exporting country.

Finally, we investigate the scenario where the exporting country commits on a division of resource deposits to serve two importing countries separately. We find that the optimal division is that which divides up the resource deposits according to the two resource-importing countries' market sizes. Interestingly, the exporting country is worse off in this case compared to the case where it has no option to divide up the resource and is required to supply the two importing countries from a common pool. Moreover, the tariff in this three-country case coincides with the tariff in the case where two importing countries form a customs union and charge the same tariff rate. This suggests that if forming a customs union that would give both importing countries higher gains from trade is not possible, an importing country may seek to ask for a commitment from the exporting country to serve it with a fixed portion of the resource deposits and, optimally, the exporting country will have to divide the resource up in a way that the tariff in the three-country case equals the tariff in the case of cooperation between the two importing countries.

The intuition behind this result is as follows. If the exporting country does not have to earmark a portion of its stock for an importing country, it can exploit the rivalry between the two importing countries. Once it is required to earmark fractions of its stock, it can no longer play one importing country off against the other.

2. A Brief Review of the Literature on Market Power in a Resources Market

The interest in the exercise of market power by suppliers of natural resource goods has given rise to the theory of resource cartels. Most papers in this area use the concepts of open-loop Nash equilibrium, or open-loop Stackelberg equilibrium. See Salant (1976), Gilbert (1978), Pindyck (1987), Ulph and Folie (1980), among others. These types of equilibriums are now known to suffer from a lack of the desirable property of subgame perfection (see Dockner et al. (2000) for an exposition of the various equilibrium concepts, such as open-loop Nash equilibrium, open-loop Stackelberg equilibrium, Markov-perfect Nash equilibrium).

Concerning market power on the demand side, there is a significant literature on the optimal tariff on exhaustible resources. Bergstrom (1981) assumes that importing countries are committed to a constant tariff rate from the initial time until the resource-exhaustion time. Brander and Djajic (1983) use the same assumption. Kemp and Long (1980) allow the tariff rate to vary over time, and show that, in the case of zero extraction cost, the optimal open-loop *ad valorem* tariff rate is a constant. They also point out that such an open-loop Stackelberg equilibrium is time-inconsistent: if the planner is released from her or his committed time path of tariff rate at some time in the future, he or she would want to choose a different tariff rate. Maskin and Newbery (1990) compute the time-consistent tariff rates. Karp and Newbery (1991, 1992) compute time-consistent tariff rates under the assumptions that importers and extractive firms do not move simultaneously.

There are a few papers that treat the case of bilateral monopoly. In a two-period model, Robson (1983) studies the extraction policy of the importing countries that also have their own resource stocks. Lewis, Lindsey and Ware (1986) consider a three-period model in which a coalition of consumers seeks a substitute for an exhaustible resource. In Harris and Vickers (1995), the resource-importing countries try to innovate to reduce their reliance on the exhaustible resource. Liski and Tahvonen (2004) study an oil-importing country's optimal carbon taxes imposed for environmental reasons. Rubio (2005) compares price setting with quantity setting in dynamic Nash and Stackelberg equilibria.

3. The Basic Model

There are n resources-importing countries that are different in terms of their marginal evaluation of the resources. Specifically, we assume that the representative individual of importing country i has the utility function

$$U_i(q_i, y_i) = Aq_i - \frac{1}{2\beta_i} q_i^2 + y_i \tag{1}$$

where q_i is her or his consumption of the resource good (called "oil" for short), and y_i is consumption of the numeraire good. Also, the consumer is endowed with a constant flow of the numeraire good. The consumer maximizes the (infinite-horizon) integral of utility discounted at the rate ρ subject to the budget constraint. This gives the inverse demand function

$$P = A - \frac{1}{\beta_i} q_i \tag{2}$$

We may call A the "choke price" of oil. If the price of oil is higher than the choke price, the demand becomes zero. In principle, choke prices may differ across countries. For simplicity, however, we shall assume that A is the same for all countries. (If choke prices were heterogeneous, the horizontal sum of the demand curves would exhibit kinks, which would render the analysis more cumbersome.) The parameter β_i can be interpreted as the size of market of country i. The larger the value of this parameter, the greater the demand for a given price of oil. If the price is the same in all countries, the world demand for oil is

$$Q(t) = B(A - P(t)) \tag{3}$$

where B is the sum of the β_i.

All the producers of oil are located in the same country, called the resource-exporting country, which consists of a continuum of identical resource-owners over the unit interval, where owner j is endowed with a stock S_{j0} of oil, and a flow $\overline{y}_j$ of the numeraire good. For simplicity, we assume that consumers in the resource-exporting country do not consume oil, so their utility is derived solely from the consumption of the numeraire good. It is linear in this good. Denoting by $E_j(t)$ owner j 's extraction rate, we define j 's accumulated extraction as

$$Z_j(t) = \int_0^t E_j(\tau)\, d\tau \tag{4}$$

Concerning extraction costs, we assume that as the stock dwindles, it becomes more and more costly to pump out a given flow. Thus we posit

$$C(E_j, Z_j) = cZ_jE_j \tag{5}$$

The marginal cost of extraction in terms of the numeraire good at time t is then $cZ_j(t)$. Thus, when $Z_j(t)$ reaches the value A/c, the marginal cost of extraction is equal to the choke price A and the firm will abandon the remaining part of its resource deposit.

We assume the initial stock is sufficiently large, in the sense that cS_{j0} is smaller than the choke price, so that when a firm abandons its deposit, it is an economic exhaustion, not a physical exhaustion of the stock. This assumption simplifies the computation of equilibrium.

If countries do not exercise their market powers, the decisions of atomistic agents result in a competitive equilibrium, and the path of accumulated aggregate extraction can be shown as

$$Z(t) = \frac{A}{c}[1 - \exp(-\kappa t)] \tag{6}$$

where

$$\kappa = \frac{1}{2}[(\rho^2 + 4Bc\rho)^{1/2} - \rho] \tag{7}$$

And the equilibrium price path is

$$P(t) = A[1 - \frac{\kappa}{cB}\exp(-\kappa t)] \tag{8}$$

The consumer surplus of the representative importing country is

$$CS_i(t) = \frac{1}{2\beta_i} q_i(t)^2 \tag{9}$$

The importing country's gain from trade, denoted by V_i^M is the (infinite-horizon) integral of the stream of discounted consumer surplus. Evaluation of the integral yields

$$V_i^M = \frac{\beta}{2}(\frac{A}{cB})^2 \frac{\kappa^2}{(\rho^2 + 4Bc\rho)^{1/2}} \tag{10}$$

Since we assume the consumers in oil-exporting country do not consume oil, the gain from trade for the oil-exporting country is just the integral of the stream of discounted profits, which is equal to

$$V^X = \frac{\beta}{\rho}(\frac{A}{cB})^2 \frac{\kappa^3}{(\rho^2 + 4Bc\rho)^{1/2}} \tag{11}$$

It can be shown that V^X is increasing in total market size, B. It is decreasing in c. Let R denote the ratio of gain from trade for the exporting country over the aggregate gains for oil-importing countries. It can be easily seen that R is increasing in B. More interestingly, the resource-exporting country's share of gains is increasing in the cost parameter c.

4. A Trade Policy Differential Game

We now turn to the case where countries interfere with the free flow of trade. We model a differential game involving n resource-importing countries and a resource-exporting country (which may be interpreted as a coalition of resource-exporting countries). We will examine both the case where the importing countries cooperate with each other to set a common tariff rate, and the case where they do not cooperate in their tariff setting.

4.1 Import tariffs and export price in a Markov-perfect Nash equilibrium

Assume that the government of each oil-importing country imposes a tariff rate, $T_i(t)$, on each unit of oil imported, and that the tariff revenue is distributed back to consumers in a lump sum fashion. Furthermore, we assume that the government of the resource-exporting country takes over the resource deposits and behaves as the monopolist. This is equivalent to taxing the export of oil at some rate $T^x(t)$. We consider the following Markovian strategies employed by resource importing and exporting countries. The monopolist announces an export price strategy which is a function of the state variable, $Z(t)$: $P^X(t) = P^X(Z(t))$ The monopolist is committed to satisfy the demand at the stated price. The price facing consumers in importing country i is $P_i^M(t) = P_i^x(Z(t)) + T_i(t)$. The monopolist's extraction is

$$E = B(A - P^X) - \sum_i \beta_i T_i \tag{12}$$

The welfare of importing country i at t is the sum of consumer surplus and tariff revenue, which can be expressed as

$$W_i(t) = \frac{\beta_i}{2}[(A - BP^X(t))^2 - T_i(t)^2] \tag{13}$$

Its objective function is to maximize the integral of the stream of discounted welfare:

$$J_i^M = \max_{T_i} \int_0^\infty (\exp(-\rho t)) \frac{\beta_i}{2}[(A - BP^X(t))^2 - T_i(t)^2]\, dt \tag{14}$$

The equilibrium concept we use is the Markov-perfect Nash equilibrium (see, *e.g.* Dockner *et al.*, 2000). According to that equilibrium concept, each player's strategy prescribes an action which is conditioned on the current level of the state variable, *i.e*. the total amount of accumulated extraction. The exporting country's strategy is $P^X(t) = P^X(Z(t))$. Importing country i announces a Markovian tariff strategy, $T_i(t) = T_i(Z(t))$. And $n + 1$ tuple of Markovian strategies $(T_1(Z),T_2(Z),...,T_n(Z),P^X(Z))$ is called a Markov-perfect Nash equilibrium if each player's strategy is a best reply to the strategies of all other players. Unlike open-loop Nash equilibriums, a Markov-perfect equilibrium is robust to deviations away from any projected equilibrium time path of plays.

Notice that by choosing Markov-perfect equilibrium as our equilibrium concept, we do not allow the players to play trigger strategies, where agents can enforce collusion by threatening to punish agents who deviate by means of reversion to the disagreement payoffs. It is known from the folk theorem in game theory that if the rate of discount is small enough, allowing punishment by trigger strategies would support a continuum of equilibriums, including the Pareto efficient outcomes. It is possible to allow for trigger strategies even in a continuous time setting, by assuming that deviations are detected only after a time lag. (See Dockner *et al*. (2000) for a discussion.)

To find a Markov-perfect Nash equilibrium, we solve a system of $n + 1$ Hamilton-Jacobi-Bellman (HJB) equations, one for each player. For importing country i, the HJB equation is

$$\rho J_i^M(Z) = \max_{T_i} [\frac{\beta_i}{2}((A - BP^X(Z))^2 - T_i^2) + \frac{dJ_i^M}{dZ}\frac{dZ}{dt}] \tag{15}$$

where

$$\frac{dZ}{dt} = B(A - P^X(Z)) - \beta_i T_i - \sum_{j \neq i} \beta_j T_j(z) \tag{16}$$

The HJB equation of the exporting country is

$$\rho J^X(Z) = \max_{P^X} [(P^X - cZ)(A - BP^X - \sum_i \beta_i T_i(Z)) + \frac{dJ^X}{dZ}\frac{dZ}{dx}] \tag{17}$$

where, from the exporter's point of view,

$$\frac{dZ}{dt} = B(A - P^X) - \sum_i \beta_i T_i(Z) \tag{18}$$

The first order condition for maximizing the right-hand side of the HJB equation (15) for importing country i with respect to T_i yields $T_i = -\frac{dJ_i^M}{dZ}$. Similarly, for the exporting country, the maximization of the right-hand side of its HJB equation (17) with respect to P^X yields

$$P^X = \frac{1}{2B}\,[BA + BcZ - B\frac{dJ^X}{dZ} - \sum_i \beta_i T^i(Z)] \tag{19}$$

We use the technique of "undetermined coefficients" to solve for the value functions. Assume the value functions J^X and J_i^M are quadratic in Z, we have

$$J^X = \omega_X + \phi_X Z + \xi_X \frac{Z^2}{2} \tag{20}$$

$$J_i^M = \omega_{M_i} + \phi_{M_i} Z + \xi_{M_i} \frac{Z^2}{2} \tag{21}$$

In addition, we impose the boundary conditions that the value functions are equal to zero when Z reaches the value A/c because, at that value, any further extraction will have a marginal cost exceeding the choke price. We can then, in principle, determine the $3(n + 1)$ coefficients by using the $(n + 1)$ HJB equations and the necessary conditions. However, the resulting equations are non linear in the coefficients, and closed form expressions for the coefficients in terms of the parameters of the model are not available, except for special cases. So, in general, we need to use numerical solutions which depend on assumed parameter values. Before doing so, let us report on special cases where a closed-form analytical solution is possible.

4.2 Bilateral monopoly

Suppose there is only one resource-importing country so that the differential game is characterized as a bilateral monopoly trade policies game. Also assume, for simplicity, that the slope of the inverse demand is unity. We get a pair of differential equations

$$\rho J^M = \frac{1}{8}\left[A - cZ + J_Z{}^X + J_Z{}^M\right]^2 \tag{22}$$

$$\rho J^M = \frac{1}{4}\left[A - cZ + J_Z{}^X + J_Z{}^M\right]^2 \tag{23}$$

It follows that $J^X(Z) = 2J^M(Z)$ and thus $J_Z{}^X(Z) = 2J_Z{}^{\mathrm{M}}(Z)$. Then

$$\rho J^M = \frac{1}{8}\left[A - cZ + 3J_Z{}^M\right]^2 \tag{24}$$

Let us conjecture that this differential equation has a solution of the form

$$J^M = \omega + \phi Z + \xi \frac{Z^2}{2}.$$

Solving for the undetermined coefficients, we get

$$J^M = \frac{1}{2\rho}\left(\frac{A\mu}{2c}\right)^2 - \left(\frac{A\mu^2}{4\rho c}\right)Z + \left(\frac{\mu^2}{4\rho}\right)\frac{Z^2}{2} \tag{25}$$

where

$\mu = \frac{2}{3}\left[(\rho^2 + 3c\rho)^{1/2} - \rho\right]$. The equilibrium strategy profile consists of $T(Z) = \left(\frac{A}{c} - Z\right)\frac{\mu^2}{4\rho}$ and $P^X(Z) = \frac{A(\rho+\mu)\mu}{2\rho c} + \frac{(2c+\mu)Z}{6}$. It can be verified that $T(A/c) = 0$ and $P^X(A/c) = A$. The value of the game (interpreted as the gain from trade under bilateral monopoly, as compared to autarky) is $J^M(0) = \left(\frac{1}{2\rho}\right)\left(\frac{A\mu}{2c}\right)^2$ for the importing country and $J^X(0) = \left(\frac{1}{\rho}\right)\left(\frac{A\mu}{2c}\right)^2$ for the exporting country. The equilibrium extraction path is $E(t) = \left(\frac{\mu A}{2c}\right)\exp\left(-\frac{\mu t}{2}\right)$. It can be shown that $\mu/2 < \kappa$ indicating that under bilateral monopoly the initial extraction rate is smaller than under perfect competition. This confirms the conventional wisdom that the monopolist is more conservationist than a perfectly competitive industry.

We can compare, for each country, the welfare under free trade with that under bilateral monopoly. For the importing country, the former is given by $V^M = \frac{1}{2}(\frac{A}{c})^2 \frac{\kappa^2}{(\rho^2 + 4c\rho)^{1/2}}$ and the latter is given by $J^M(0) = \left(\frac{1}{2\rho}\right)\left(\frac{A\mu}{2c}\right)^2$. It follows that, for the resource-importing country, free trade is better than bilateral monopoly if the extraction cost parameter, c, is small, while the opposite is true if c is large. For the resource-exporting country, free trade is worse than bilateral monopoly if the extraction cost parameter, c, is small, while the opposite is true if c is large.

4.3 Cooperative tariff setting by resource-importing countries

Now assume that the resource-importing countries form a customs union and imposes a common tariff rate on oil. The exporting country chooses a price strategy $P^X = P^X(Z)$ as a best reply to the tariff policy $T^{CU} = T^{CU}(Z)$ of the customs union. The tariff policy must maximize the customs union's objective function

$$J^{CU} = \max_T \int_0^\infty (\exp(-\rho t)) \sum_i \frac{\beta_i}{2} [(A - BP^X(t))^2 - T(t)^2]\, dt \tag{26}$$

Proceeding in the same way as in subsection 3.2, we obtain the following differential equations that characterize the value functions

$$\rho J^{CU} = \frac{B}{8}\left[A - cZ + J_Z{}^X + J_Z{}^{CU}\right]^2 \tag{27}$$

$$\rho J^X = \frac{B}{4}\left[A - cZ + J_Z{}^M + J_Z{}^X\right]^2 \tag{28}$$

Let $\lambda = (\rho^2 + 3Bc\rho)^{1/2} - \rho$. As before, we impose the boundary conditions that the value functions are equal to zero when Z reaches the value A/c. It can then be verified that the differential equations (27) and (28) have the following solutions

$$J^{CU} = \frac{\lambda^2}{18B\rho} Z^2 - \frac{A\lambda^2}{9Bc\rho} Z + \frac{\lambda^2}{18Bc\rho}\left(\frac{A}{c}\right)^2 \tag{29}$$

$$J^X = \frac{\lambda^2}{9B\rho} Z^2 - \frac{2A\lambda^2}{9Bc\rho} + \frac{\lambda^2}{9Bc\rho}\left(\frac{A}{c}\right)^2 \tag{30}$$

Note that, although every country in the trade bloc charges the same tariff rate, their welfare can be different due to different market size β_i. Indeed, the gain from trade for each importing country i is $J_i{}^M = \frac{\beta_i}{B} J^{CU}$.

4.4 Non-cooperative tariff setting by heterogeneous importing countries

As mentioned above, if there are two or more resource-importing countries setting tariff rates non-cooperatively, we would not be able to obtain any analytical solution. To simplify the analysis, we consider the case where there are one resource-exporting and two resource-importing countries. The relationship among the three HJB equations is not trivial even in the symmetric importing countries' case. We will obtain nine equations that, in principle, determine nine unknowns (coefficients), ω_i, ϕ_i and ξ_i. However, these coefficients are not solvable analytically. In order to obtain some insight, we have calculated numerical solutions for these coefficients by setting $A = 100$, $c = 0.25$ and

$\rho = 0.05$. We would like to see how the market size, and the difference between β_1 and β_2 holding total market size B constant, affect their welfare levels as well as the exporting country's welfare in various competition modes namely, free trade, non-cooperative tariff war, and cooperative tariff setting. The welfare for two importing countries under free trade, tariff war, and cooperation are given in Tables 1, 2, and 3.

Table 1: Welfare levels of importing countries under free trade

	$\beta_1 = \beta_2$	$\beta_1 = 1.5\beta_2$	$\beta_1 = 2\beta_2$	$\beta_1 = 3\beta_2$	$\beta_1 = 4\beta_2$
B = 1	1400,1400	1681,1120	1867,934	2101,700	2240,560
B = 2	1140,1140	1368,912	1520,760	1710,570	1824,456
B = 3	990,990	1188,792	1320,660	1485,495	1584,396
B = 4	889,889	1067,711	1185,593	1333,444	1422,356

Table 1 gives the welfare levels of two importing countries under free trade. Given the total market size B, the sum of welfare levels is the same regardless of the relative size of the importing country. As the total market size gets bigger, the sum of the welfare of the importing countries gets smaller. (Thus, for a given stock of resource to be exploited, the consumer surplus triangle gets smaller as the demand curve becomes flatter.)

Table 2: Welfare levels of importing countries under trade war with non-cooperative tariff setting

	$\beta_1 = \beta_2$	$\beta_1 = 1.5\beta_2$	$\beta_1 = 2\beta_2$	$\beta_1 = 3\beta_2$	$\beta_1 = 4\beta_2$
B = 1	1173,1173	1409,971	1597,846	1888,690	2109,592
B = 2	1097,1097	1315,917	1496,807	1788,674	2020,590
B = 3	1017,1017	1218,854	1388,757	1669,639	1896,566
B = 4	951,951	1139,801	1299,712	1567,606	1787,541

Table 2 gives welfare levels of two importing countries under trade war with a non-cooperative tariff setting. Observe that the sum of their welfare decreases as the total market size gets bigger (similar to the free trade results in Table 1, but the rate of decrease is slower than under free trade). In fact, with B sufficiently large and the two countries sufficiently different from each other, the sum of their welfare levels in Table 2 is larger than in Table 1, see for example when $B = 2$ and $\beta_1 = 3\beta_2$. Indeed, if $B = 4$, the welfare under tariff war with non-cooperative tariff setting will be higher than that under free trade for each value of β, where $\beta = 1,(3/2),2,3,4$. So, as the total market size increases, the importing country is more likely to be better off under tariff war than under free trade. Given the total market size B, as the degree of asymmetry between the two importing countries increases, the sum of their welfare levels increases (in sharp contrast to the free case in Table 1). Notice that for small B ($B = 1,2$), the welfare under free trade is higher starting from a symmetric market size but, as the degree of asymmetry increases, the welfare under tariff war with a non-cooperative tariff setting eventually becomes higher for both importing countries. Therefore, we conclude that the welfare for importing countries is likely to be higher under tariff war with non-cooperative tariff setting than that under free trade if they are more asymmetric in their market size.

Table 3: Welfare levels of importing countries under trade war with cooperative tariff setting

	$\beta_1 = \beta_2$	$\beta_1 = 1.5\beta_2$	$\beta_1 = 2\beta_2$	$\beta_1 = 3\beta_2$	$\beta_1 = 4\beta_2$
B = 1	2000,2000	2400,1600	2667,1333	3000,1000	3200,800
B = 2	2318,2318	2782,1855	3091,1546	3477,1159	3709,927
B = 3	2477,2477	2972,1981	3302,1651	3715,1238	3963,991
B = 4	2577,2577	3092,2061	3436,1718	3866,1288	4123,1031

Table 3 gives welfare levels of two importing countries under cooperative tariff setting. In sharp contrast to Tables 1 and 2, as B gets bigger, the sum of their welfare levels gets bigger. Given the total market size, the sum of the welfare levels of the two importing countries is constant, regardless of their relative degree of asymmetry (in sharp contrast to Table 2).

Table 4: Welfare of the exporting country

	Free trade	**Customs union**	**Non-coop**	**Non-coop**	**Non-coop**	**Non-coop**	**Non-coop**
			$\beta_1 = \beta_2$	$\beta_1 = 1.5\beta_2$	$\beta_1 = 2\beta_2$	$\beta_1 = 3\beta_2$	$\beta_1 = 4\beta_2$
B = 1	10034	8000	9919	9877	9800	9633	9484
B = 2	12317	9273	11981	11935	11849	11661	11487
B = 3	13480	9907	13078	13032	12947	12756	12578
B = 4	14222	10307	13796	13752	13668	13481	13304

Table 4 reports the welfare level of the exporting country. In contrast with the importing countries, the welfare of the exporting country increases as the total market size, B, increases under all cases (free trade, non-cooperative tariff setting, and, cooperative tariff setting). Also, different than importing countries, its welfare is the lowest if the importing countries form a custom union compared to free trade and non-cooperative tariff war. Moreover, free trade is better for the exporting country than tariff war. Under tariff war with non-cooperative tariff setting, when the importing countries are more asymmetric in their market sizes, the exporting country's welfare decreases. Therefore, it would prefer the symmetric importing countries case. This is not so under free trade and under cooperative tariff setting, where we can show that the ratio β_1/β_2 has no impact on the welfare of the exporting country.

Table 5: The ratio of welfare levels of two importing countries under trade war with non-cooperative tariff setting

	$\beta_1 = \beta_2$	$\beta_1 = 1.5\beta_2$	$\beta_1 = 2\beta_2$	$\beta_1 = 3\beta_2$	$\beta_1 = 4\beta_2$
B = 1	1	1.45	1.89	2.74	3.56
B = 2	1	1.43	1.85	2.65	3.42
B = 3	1	1.43	1.83	2.61	3.35
B = 4	1	1.42	1.82	2.59	3.30

Table 5 gives the ratio of welfare levels of two importing countries under trade war with non-cooperative tariff setting. Country 1 is the larger country. As mentioned before, under free trade or custom union, the ratio of welfare levels is identical to the ratio of market sizes. This is not the case under trade war with non-cooperative tariff setting. The numbers in Table 5 supports the notion of free riding for the smaller country in the noncooperative tariff setting game.

5. Optimal deposit division

In this section, we consider a special scenario, where the resource exporting country is forced to divide its oil deposit to serve two importing countries separately. Think of a resource deposit that has a rectangular shape with a depth which is great enough to ensure abandonment before exhaustion. Normalize the length of the deposit to unity. The exporting country has to specify the length of $\alpha \in (0,1)$, and cut the deposit into two parts to serve two importing countries separately. Without loss of generality, assume it uses the field with length equals to α to serve importing country 1 and the remaining field, with length $1 - \alpha$, to serve importing country 2. We have a two-stage game structure. This problem can be solved by backward induction. In the second stage, given α, the resource exporting country plays with each importing country separately in choosing the price of oil. As we showed earlier, the analytical solution can be obtained in the case of bilateral monopoly. We can thus find the equilibrium welfare for exporting country as a function of α.

In the first stage, the exporting country chooses the optimal division, α, to maximize its welfare expression V^X defined below

$$V^X = 2A^2\alpha\psi(\alpha) + 2A^2(1-\alpha)\chi(\alpha) \tag{31}$$

where we define

$$\psi(\alpha) = \beta_1 / \left(6c\beta_1 + 4\alpha\rho + (\alpha\rho^2 + 3c\beta_1\rho)^{1/2}(\alpha)^{1/2}\right) \tag{32}$$

$$\chi(\alpha) = \beta_2 / \left(6c\beta_2 + 4(1-\alpha)\rho + ((1-\alpha)\rho^2 + 3c\beta_2\rho)^{1/2}(1-\alpha)^{1/2}\right) \tag{33}$$

We can show that the first order conditions are satisfied if the exporting country sets $\alpha = \beta_1 / B$ and the second order conditions are also satisfied. This implies that the exporting country should divide the resource to serve two countries according to their relative market size. Interestingly, if $\alpha = \beta_1/B$, the two importing countries will charge the same tariff rate and this rate is equal to the cooperative rate as mentioned in the previous section. We know that the cooperation make the importing countries better off and the exporting country worse off in the original differential game. It follows that, if the exporting country is forced to commit right from the beginning to a fixed (though optimally chosen) division, its welfare will be lower than the non-commitment case. Another implication is that if forming a coalition of two importing countries is not possible, an importing country can gain by forcing the oil exporting country to commit on a fixed division of its deposit to serve it.

6. Concluding Remarks

By setting up a model of dynamic trade policy war between a country which extracts an exhaustible resource and one or more resource-importing countries, we have been able to obtain a number of interesting results. In the case of one importing country, we are able to obtain analytically the Markov perfect equilibrium strategies for tariff rate and export price. We then compare the tariff war equilibrium with the free trade equilibrium. We find that the initial extraction rate under bilateral monopoly is lower than that under free trade. This is consistent with the notion that the monopolist conserves the resources. Furthermore, we determine the effects of a higher extraction cost or higher discount rate on the welfare level of a resource importing country, and of a resource exporting country. The lower the extraction cost parameter, the more likely the resource exporting (importing) country is going to be better (worse) off under tariff war compared to free trade. Indeed, there exists a threshold level of marginal cost parameter beyond which the oil importing country benefits from bilateral monopoly, and the higher the rate of discount, the greater is the corresponding threshold marginal cost level. We also obtain some results for the division of gains from trade between the two countries. The resource-exporting country's share of gains is increasing in the cost parameter and decreasing in the discount rate under free trade equilibrium. Under tariff war, two-thirds of gains from trade accrue to the resource-exporting countries regardless of parameter values.

We also generalize the model to the case of multiple resource-importing countries to analyze the effect of asymmetry between importing countries' market sizes on their welfare under various competition modes, namely, free trade, trade war with non-cooperative tariff setting, and custom union. Due to the complexity of the HJB equations, the analytical solution is not obtainable, so we can only obtain numerical solutions by specifying numerical values to model parameters. In the case of two importing countries and one exporting country, we find that each importing country's welfare is decreasing in the total market size under either free trade or trade war with non-cooperative tariff setting, but increasing under a custom union formed by two importing countries. The exporting country's welfare is always increasing in market size. Another interesting result is that as the asymmetry between two importing countries' market sizes increases, the exporting country's welfare decreases in both the free trade case and the case of trade war with non-cooperative tariff setting, while the sum of gains by importing countries increases. The exporting country's welfare is always higher in the free trade scenario compared to trade war (with non-cooperative tariff setting) regardless of the degree of asymmetry. In contrast, whether free trade is better for an importing country as compared to trade war (with non-cooperative tariff setting) depends on how asymmetric the market sizes are.

We discuss a special case where the exporting country has to commit on a division of its deposit of resource to serve to two countries separately. We argue that the optimal division is the one which splits the deposit according to importing countries' relative market size. The corresponding tariffs are the same as in the case where they form a custom union. This implies that the exporting country is worse off compared to the case where it serves two importing countries with a common deposit.

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