EFFORT SUBSIDIES AND ENTRY DETERRENCE IN TRANSBOUNDARY FISHERIES*

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ABSTRACT. This paper analyzes a two-stage game, based on the Gordon-Schaefer model of the fishery, to examine the strategic entry-deterring role for effort subsidies in noncooperative transboundary fisheries. The game reveals that a country, whose domestic fleet has an effort cost advantage over a rival foreign fleet, may choose to subsidize domestic effort to the point that foreign entry in the fishery becomes unprofitable. Whether the outcome of the game is characterized by foreign entry deterrence or accommodation, and whether it is also characterized by a domestic effort subsidy or a tax, depends on domestic and foreign effort costs and the number of firms in each fleet. The various outcomes of the game analyzed here help to explain the persistence of subsidies in some world fisheries.

KEY WORDS: fisheries subsidies, entry deterrence, noncooperative games.

PROPOSED RUNNING HEAD: Effort Subsidies and Entry Deterrence

1 Introduction

In recent years, the problem of fisheries subsidies has become a global concern. Upon estimating worldwide fisheries revenues and costs in 1989, the United Nations Food and Agriculture Organization [1992] concluded that countries may have provided as much as $54 billion in fisheries subsidies that year, in spite of apparent excess fishing capacity and declining fish stocks.[1] While a number of studies (see, for example, Gréboval [1999], World Wildlife Fund [1997], and Porter [1997]) describe the consequences of effort-enhancing fisheries subsidies, there are few explanations for their persistence under such uneconomical and unsustainable conditions. One recent explanation put forward by Ruseski [1998] focuses on the strategic rent-shifting role for effort subsidies in noncooperative transboundary fisheries.[2] This paper extends the game-theoretic analysis presented in Ruseski to reveal another strategic role for effort subsidies in these fisheries: entry deterrence.

The game analyzed here involves two stages and two countries, hereafter referred to as the domestic country and the foreign country, with access to the same fish stock. Each country has a fishing fleet comprised of one or more competitive firms. In the first stage, the domestic country chooses an effort policy (an effort tax or a subsidy) for its fleet. In the second stage, the firms in both fleets choose their individual effort levels in the fishery competitively. Thus the domestic country uses its effort policy in the first stage to influence

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[1] Using a more precise approach than that of the United Nations Food and Agriculture Organization, Milazzo [1996] estimates that worldwide fisheries subsidies are in the range of $15-20 billion annually, or that subsidies represent 20-25 percent of worldwide fisheries revenues.

[2] The United Nations Convention on the Law of the Sea [UNCLOS] defines transboundary fisheries as fisheries that are prosecuted on fish stocks lying within two or more coastal exclusive economic zones (shared stocks), or on fish stocks lying within one or more coastal exclusive economic zones and the adjacent high seas (straddling stocks). The analysis presented here can also be applied to fisheries prosecuted on fish stocks lying entirely in the high seas (high seas stocks). One common characteristic of these stocks is that more than one country has access to them. As a result, in the absence of a binding cooperative agreement between countries, these stocks will be subject to noncooperative international exploitation.

the competitive outcome in the second stage. The game is different from Ruseski [1998] in two key respects. First, to simplify matters, only the domestic country is allowed to choose its effort policy with a view to influencing the outcome in the second stage. Second, to make entry deterrence a possible outcome in the second stage, domestic and foreign effort costs are allowed to be different.

As expressed by a referee, there are two considerations for the domestic country. On the one hand, because there may be multiple competitive firms in the domestic fleet, there is the potential for domestic rent dissipation in the fishery. Therefore, without any threat of foreign competition, the optimal domestic effort policy would be an efficiency-inducing effort tax. On the other hand, if there is a threat of foreign competition, then there is an incentive for the domestic country to reduce the effort tax, or even to provide an effort subsidy. Doing so would induce more domestic effort, thereby giving the domestic fleet a competitive advantage vis-à-vis the foreign fleet and enabling it to capture more rent. Moreover, if the domestic fleet has an effort cost advantage over the foreign fleet, then the domestic country could even choose to subsidize domestic effort to the point that foreign entry in the fishery becomes unprofitable. Whether the outcome of the game is characterized by foreign entry deterrence or accommodation, and whether it is also characterized by a domestic effort subsidy or a tax, depends on domestic and foreign effort costs and the number of firms in each fleet.

The foundation for this paper is the steady-state, or static, analysis of common property resource exploitation presented in Mesterton-Gibbons [1993]. In showing how the problem of the commons has the form of a noncooperative game, Mesterton-Gibbons considers a single-stage Nash game in effort levels between a fixed number of potential exploiters of the commons that are differentiated from each other by their effort costs. In this paper, however, the effort cost of a sub-group of these potential exploiters is made endogenous by the ability of the domestic country to provide a degree of effort subsidization to its fleet. Thus the single-stage game in Mesterton-Gibbons is extended to a two-stage game in which the Nash game in domestic and foreign effort levels is preceded by a Stackelberg game in the domestic effort policy.

This paper contributes to the literature on noncooperative games and international common property fisheries that began with Levhari and Mirman [1980]. The notion of entry deterrence in fisheries is considered by Clark [1980], whose dynamic closed-loop game suggests that, if one exploiter of a fishery has a harvesting cost advantage over another exploiter, entry deterrence of one form or another always occurs. If the cost advantage is large, then entry deterrence is a by-product of efficient harvesting by the low-cost exploiter. If the cost advantage is small, then entry deterrence results from strategically inefficient over-harvesting by the low-cost exploiter. Like Clark, the static game analyzed here suggests that foreign entry deterrence and domestic efficiency can occur simultaneously if the domestic effort cost advantage is sufficiently large. Unlike Clark, however, the game also suggests that foreign entry deterrence may not occur if the domestic effort cost advantage is sufficiently small. Similar results are found by Crabbé and Long [1993] in their dynamic open-loop game of foreign entry deterrence in an international common property fishery. Unlike the game analyzed here, however, Crabbé and Long require foreign open access (i.e. an infinite number of firms in the foreign fleet) for complete entry deterrence to occur.

Mason and Polasky [1994] consider entry deterrence in the commons using a different framework. In their two-period game, there is a single incumbent exploiter of a resource in the first period facing the threat of entry by another exploiter in the second period.

Mason and Polasky show that, if the potential entrant has a sufficiently high fixed cost, the incumbent will choose to over-harvest the resource in the first period, thereby raising variable costs in the commons in the second period to the point that the potential entrant cannot profit from harvesting any of the resource. The game analyzed here applies similar thinking except that, rather than allowing the domestic fleet to harvest before the foreign fleet, the domestic country is allowed to pre-commit to an effort policy that induces over-harvesting by its fleet. The result is an intuitively appealing explanation for the persistence of subsidies in some world fisheries that, to our knowledge, has not been considered before.

The analysis of international common property fisheries is most often conducted in a dynamic framework. It should thus be recognized that the static game analyzed here abstracts from potentially important strategic dynamic effects, such as the effects of a change in fleet size examined by Mason and Polasky [1997]. However, one of the key features of the static framework, aside from its relative analytical simplicity, is its compelling similarity to the strategic international trade policy literature (see Brander [1995] for a useful survey). For example, Brander and Spencer [1985] consider two countries whose domestic firms export an identical product to a foreign market. Using a two-stage game similar to the one considered here and in Ruseski [1998], Brander and Spencer show that each country has a unilateral incentive to provide an export subsidy to its industry. By doing so, each country perceives that it will give its domestic firm a competitive advantage in the foreign market and thereby enable it to capture more profits. Thus, while Brander and Spencer [1985] develop the strategic rent-shifting role for export subsidies in the context of *international trade wars*, the game analyzed here develops the strategic entry-deterring role for effort subsidies in the context of *international fish wars*.

The rest of the paper proceeds as follows. Section 2 presents the Gordon-Schaefer model of the noncooperative two-country fishery. Section 3 derives the effort levels of both fleets and the size of the fish stock in the second stage of the game, as functions of domestic and foreign effort costs, fleet sizes, and the domestic effort policy. Section 4 presents the subgame perfect equilibrium solution for the domestic effort policy in the first stage, as well as fleet effort levels and the size of the fish stock in the second stage, as functions of domestic and foreign effort costs and fleet sizes. This section also presents a numerical simulation and a geometrical interpretation of the solution. Finally, Section 5 provides a summary and some concluding remarks.

2 The Model

There is a single fish stock of size x that evolves over time according to the Gordon-Schaefer model of a fishery (see Gordon [1954] and Schaefer [1957]). Its dynamic equation is

$$\frac{dx}{dt} = G(x) - \sum_{i=1}^{2} H_i, \tag{1}$$

where the first term on the right hand side is the natural growth function and the second term is the sum of harvests by the fleets of a domestic country and a foreign country, denoted 1 and 2, respectively. The natural growth function is

$$G(x) = rx\left(1 - \frac{x}{K}\right), \tag{2}$$

where r is the intrinsic rate of growth and K is the carrying capacity of the fishing ground. The harvest function for each fleet is linear in its effort level and the size of the stock,

$$H_i = qE_ix, \ \ i = 1, 2, \tag{3}$$

where the catchability coefficient q is assumed to be the same for both fleets, so that neither fleet has a technological advantage over the other.

Assuming that objective functions are based on steady-state values, the dynamic equation can be set equal to zero and combined with the natural growth and harvest functions to reveal the unique steady-state size of the fish stock as a function of the effort levels of both fleets,

$$x = \frac{K}{r}\left(r - q\sum_{i=1}^{2} E_i\right). \tag{4}$$

The fishery is modeled as a noncooperative two-stage game. In the second stage, firms in each fleet choose their individual effort levels, taking the effort levels chosen by rival firms in both fleets and the domestic effort policy as given. In the first stage, the domestic country chooses an effort policy for the firms in its fleet, taking the number of firms in both fleets as given, with the full knowledge of how its effort policy influences the competitive outcome in the second stage. The game is solved for the subgame perfect equilibrium domestic effort policy, domestic and foreign effort levels, and the steady-state size of the fish stock, using the method of backward induction.

3 Effort Levels and Stock Size in the Second Stage

Turning first to the second stage, suppose that there are $n_1 \geq 1$ identical firms in the domestic fleet and $n_2 \geq 1$ identical firms in the foreign fleet. Using the single stage analysis presented in Mesterton-Gibbons [1993], which is also similar to an approach used by Dasgupta and Heal [1979, p. 56], the vth firm in the domestic fleet ($v \in n_1$) solves the problem of maximizing its individual steady-state profit from the fishery by choosing its individual effort level e_{1v},

$$\max_{e_{1v}} \pi_{1v} = pqe_{1v}x - (c_1 - s_1)e_{1v}, \tag{5}$$

where p is the price per unit of harvest faced by firms in both fleets, c_1 is the cost per unit of effort faced by firms in the domestic fleet, and s_1 is the effort policy faced by firms in the domestic fleet. Since there is no restriction on the sign of the effort policy, $s_1 > 0$ implies an effort subsidy while $s_1 < 0$ implies an effort tax. Each firm takes into account the effect of its own effort level on the steady-state size of the fish stock, but takes as given the effort levels of rival firms in both fleets. Thus, from the perspective of the vth firm in the domestic fleet, the steady-state size of the fish stock can be re-written as

$$x = \frac{K}{r}\left(r - qe_{1v} - q\sum_{w \neq v}^{n_1} e_{1w} - qE_2\right). \tag{6}$$

Using symmetry on the first-order condition for e_{1v}, i.e., $e_{1v} = e_1$ for all $v \in n_1$, solving for e_1, and then multiplying by n_1 yields the reaction function of the domestic fleet to the effort level chosen by the foreign fleet in the second stage,

$$E_1 = \begin{cases} \dfrac{n_1\left[r(1 - b_1 + d_1) - qE_2\right]}{q(1+n_1)}, & \text{if } r(1 - b_1 + d_1) > qE_2 \\ 0, & \text{otherwise,} \end{cases} \tag{7}$$

where $b_1 = c_1/(pqK)$ and $d_1 = s_1/(pqK)$. One may think of b_1 as a dimensionless measure of the domestic cost of effort in the fishery. It is assumed that $b_1 < 1$ to ensure that there would be a positive level of effort in the fishery if it were under the sole jurisdiction of the domestic country. The parameter d_1 may be thought of as a dimensionless measure of the domestic effort policy. Once again, since there is no restriction on the sign of the effort policy, $d_1 > 0$ implies an effort subsidy while $d_1 < 0$ implies an effort tax.

Similarly, the reaction function of the foreign fleet to the effort level chosen by the domestic fleet in the second stage is

$$
E_2 = \begin{cases} \dfrac{n_2\left[r(1-b_2) - qE_1\right]}{q(1+n_2)}, & \text{if } r(1-b_2) > qE_1 \\[2ex] 0, & \text{otherwise,} \end{cases} \tag{8}
$$

where it can be assumed that either $b_2 = c_2/(pqK)$ and $s_2 = 0$, or $b_2 = (c_2 - s_2)/(pqK)$ and s_2 is some constant that does not change throughout the game (in either case it is also assumed that $b_2 < 1$ to ensure that there would be a positive level of effort in the fishery if it were under the sole jursidiction of the foreign country). That is, either there is no foreign effort policy at all, or the foreign effort policy (which could be an effort subsidy or an effort tax) is not chosen with a view to influencing the outcome of competitive international harvesting in the second stage.

The second-stage effort levels chosen by the domestic and foreign fleets, as functions of fleet sizes, effort costs, and the domestic effort policy to be determined in the first stage, may be determined as the point of intersection of the reaction curves given in (7) and (8) in the effort plane. Depending on parameter values, these reaction curves may intersect at a point on the E_1 axis (such that $E_1 > 0$ and $E_2 = 0$), a point on the E_2 axis (such that $E_1 = 0$ and $E_2 > 0$), or at an interior point (such that $E_1 > 0$ and $E_2 > 0$). Defining

$$
\alpha = -\frac{1 - b_1 + n_2\left(b_2 - b_1\right)}{1 + n_2} \tag{9}
$$

and

$$
\beta = \frac{1 - b_2 - n_1\left(b_2 - b_1\right)}{n_1}, \tag{10}
$$

analysis of the three cases gives fleet effort levels in the second stage as

$$E_1 = \begin{cases} 0, & \text{if } \mathrm{d}_1 \leq \alpha \\ \dfrac{rn_1 \left[1 - b_1 + d_1 + n_2 \left(b_2 - b_1 + d_1\right)\right]}{q \left(1 + n_1 + n_2\right)}, & \text{if } \alpha < \mathrm{d}_1 < \beta \\ \dfrac{rn_1 \left(1 - b_1 + d_1\right)}{q \left(1 + n_1\right)}, & \text{if } \beta \leq \mathrm{d}_1 \end{cases} \tag{11}$$

and

$$E_2 = \begin{cases} \dfrac{rn_2 \left(1 - b_2\right)}{q \left(1 + n_2\right)}, & \text{if } \mathrm{d}_1 \leq \alpha \\ \dfrac{rn_2 \left[1 - b_2 - n_1 \left(b_2 - b_1 + d_1\right)\right]}{q \left(1 + n_1 + n_2\right)}, & \text{if } \alpha < \mathrm{d}_1 < \beta \\ 0, & \text{if } \beta \leq \mathrm{d}_1. \end{cases} \tag{12}$$

Using (11) and (12) in (4), gives the steady-state size of the fish stock in the second stage as

$$x = \begin{cases} \dfrac{K \left(1 + n_2 b_2\right)}{1 + n_2}, & \text{if } \mathrm{d}_1 \leq \alpha \\ K \left[1 + n_1 \left(b_1 - d_1\right) + n_2 b_2\right], & \text{if } \alpha < \mathrm{d}_1 < \beta \\ \dfrac{K \left[1 + n_1 \left(b_1 - d_1\right)\right]}{1 + n_1}, & \text{if } \beta \leq \mathrm{d}_1. \end{cases} \tag{13}$$

4 Domestic Effort Policy in the First Stage

The domestic country chooses its effort policy with the objective of maximizing domestic rent from the fishery, W_1, which is assumed to equal the profit of the domestic fleet, $pqE_1x - (c_1 - s_1)E_1$, net of the domestic effort policy, s_1E_1,

$$W_1 = pqE_1x - (c_1 - s_1)E_1 - s_1E_1 = pqE_1x - c_1E_1. \tag{14}$$

The domestic country chooses d_1 with the full knowledge of how its choice influences E_1, E_2, and x in the second stage, as shown in (11)-(13). As will be shown next, the solution to this problem can lead to various outcomes, depending on domestic and foreign effort costs and the number of firms in each fleet.

4.1 Domestic Effort Policy without the Threat of Foreign Entry

This section considers the choice of domestic effort policy when there is no threat of entry by the foreign fleet, i.e., for this section only, let $n_2 = 0$ and $b_2 = 1$ in (9) - (13) above. In this case, the domestic country can use its effort policy to fully internalize the externality arising from competitive harvesting between the $n_1 \geq 1$ domestic firms in its fleet and thereby achieve domestic efficiency in the fishery. Using (9) - (13) in (14) and applying the first-order condition for a maximum results in

$$\tilde{d}_1 = \left(\frac{1-n_1}{n_1}\right)\left(\frac{1-b_1}{2}\right). \tag{15}$$

Thus, for any $n_1 > 1$ domestic efficiency in the fishery requires an effort tax, i.e., $\tilde{d}_1 < 0$, and for $n_1 = 1$ domestic efficiency does not require any effort policy at all, i.e., $\tilde{d}_1 = 0$. The corresponding level of domestic effort in the fishery is $\tilde{E}_1 = r(1-b_1)/(2q)$ and the corresponding steady-state size of the fish stock is $\tilde{x} = K(1+b_1)/2$. Even though $n_2 = 0$ and $b_2 = 1$ are ruled out in the game considered in the rest of the paper, the efficient domestic effort policy shown in (15) still turns out to be part of the subgame perfect equilibrium solution. The next section considers the circumstances in which this and other (inefficient) outcomes can occur.

4.2 Domestic Effort Policy with the Threat of Foreign Entry

This section considers the various outcomes of the game in which there is a threat of entry by the foreign fleet, i.e., $n_2 \geq 1$ and $b_2 < 1$ in (9) - (13) above. Two situations are considered: first, when the domestic cost of effort is less than the foreign cost of effort and second, when the domestic cost of effort is greater than the foreign cost of effort (see Ruseski [1998] for an examination of the special case in which domestic and foreign effort costs are equal).

4.2.1 Domestic Effort Cost Advantage

It is assumed here that $b_1 < b_2$, so that the domestic cost of effort in the fishery is less than the foreign cost of effort. Using (11) and (13) in (14), domestic rent from the fishery can be interpreted mathematically as a piecewise quadratic function of the domestic effort policy,

$$W_1 = \begin{cases} 0, & \text{if } \mathrm{d}_1 \leq \alpha, \\ f(d_1), & \text{if } \alpha < \mathrm{d}_1 < \beta, \\ g(d_1), & \text{if } \beta \leq \mathrm{d}_1, \end{cases} \tag{16}$$

where α and β are defined in (9) and (10), and f and g are certain quadratic functions in d_1, with negative leading coefficient. A direct calculation shows that the quadratic $f(d_1)$ has a maximum at

$$d_1 = \hat{d}_1 \overset{d}{=} \frac{(1-n_1+n_2)\left[1-b_1+n_2(b_2-b_1)\right]}{2n_1(1+n_2)}, \tag{17}$$

while $g(d_1)$ has a maximum at

$$d_1 = \tilde{d}_1 \overset{d}{=} \frac{(1-n_1)(1-b_1)}{2n_1}. \tag{18}$$

Using (17) and (18) and the assumption that $b_1 < b_2$, it follows that, regardless of the magnitudes of n_1 and n_2, $\alpha < \widehat{d}_1$ and $\widetilde{d}_1 < \widehat{d}_1$. For later use, we also record the identities

$$\beta - \widehat{d}_1 = \frac{\left[(b_1 - b_2)(1 + n_2) + 1 - b_2\right](1 + n_1 + n_2)}{2n_1(1 + n_2)} \tag{19}$$

and

$$\widetilde{d}_1 - \beta = \frac{(2b_2 - b_1 - 1)(1 + n_1)}{2n_1}. \tag{20}$$

Finally, note that $b_1 < b_2$ implies that $\alpha < \beta$ and $\alpha < 0$, but β can be either positive or negative. The following proposition describes the conditions that determine whether the outcome of the game is characterized by foreign entry deterrence or accommodation, and whether it is accompanied by domestic efficiency or inefficiency, when there is a domestic effort cost advantage.

Proposition 1 *In subgame perfect equilibrium, if the domestic country has an effort cost advantage over the foreign country, such that $b_1 < b_2$, then the outcome of the game can be characterized by one of three possibilities, depending on domestic and foreign effort costs and the number of firms in the foreign fleet:*

Case 1. If $(1 + b_1)/2 < b_2$, regardless of n_2, then the outcome is characterized by domestic efficiency and foreign entry deterrence;

Case 2. If $[b_1(1 + n_2) + 1]/(2 + n_2) \leq b_2 \leq (1 + b_1)/2$, then the outcome is characterized by domestic inefficiency and foreign entry deterrence;

Case 3. If $b_2 < [b_1(1 + n_2) + 1]/(2 + n_2)$, then the outcome is characterized by domestic inefficiency and foreign entry accommodation.

Proof. Let d_1^* denote the effort policy that maximizes domestic rent from the fishery. Depending on parameter values, the point d_1^* will lie in the interior of one of the two intervals

(β, ∞) or (α, β), or will coincide with the boundary point β.

Suppose the parameter values are such that $(1+b_1)/2 < b_2$ for any n_1 and n_2, as in Case 1. Using (18)-(20) it follows that

$$\tilde{d}_1 > \beta. \tag{21}$$

From (19) and our earlier observation that $\tilde{d}_1 < \hat{d}_1$, we deduce that

$$\hat{d}_1 > \beta. \tag{22}$$

But, (22) implies that W_1 is monotonic increasing on the interval (∞, β), and (21) implies that W_1 is monotonic increasing on $(\beta, \tilde{d}_1)$ and monotonic decreasing on $(\tilde{d}_1, \infty)$, so the unique maximum of W_1 occurs at $d_1^* = \tilde{d}_1$, which lies in the interior of the interval (β, ∞). Thus, using (11)-(13) and (18), the subgame perfect equilibrium outcome in Case 1 has

$$\begin{aligned}
d_1^* &= \left(\frac{1-n_1}{n_1}\right)\left(\frac{1-b_1}{2}\right), \\
E_1^* &= \frac{r\,(1-b_1)}{2q}, \\
E_2^* &= 0, \\
x^* &= \frac{K\,(1+b_1)}{2}.
\end{aligned}$$

Suppose the parameter values are such that $[b_1(1+n_2)+1]/(2+n_2) \leq b_2 \leq (1+b_1)/2$, as in Case 2. It follows from (19) and (20) that $\hat{d}_1 \geq \beta$ and $\tilde{d}_1 \leq \beta$, so W_1 is monotonic increasing on $(-\infty, \beta)$ and monotonic decreasing on (β, ∞) with a unique maximum at $d_1^* = \beta$. Thus, using (11)-(13), the subgame perfect equilibrium outcome in Case 2 has

$$\begin{aligned}
d_1^* &= \frac{1 - b_2 - n_1 (b_2 - b_1)}{n_1}, \\
E_1^* &= \frac{r (1 - b_2)}{q}, \\
E_2^* &= 0, \\
x^* &= K b_2.
\end{aligned}$$

Suppose the parameter values are such that $b_2 < [b_1(1 + n_2) + 1]/(2 + n_2)$, as in Case 3. It follows from (19) that $\widehat{d}_1$ belongs to the interval (α, β), so W_1 is monotonic increasing on $(-\infty, \widehat{d}_1)$, and monotonic decreasing on $(\widehat{d}_1, \beta)$. But $\widetilde{d}_1 < \widehat{d}_1 < \beta$, so W_1 is also decreasing on (β, ∞). Hence $d_1^* = \widehat{d}_1$, which lies in the interior of the interval (α, β). Thus, using (11)-(13) and (17), the subgame perfect equilibrium outcome in Case 3 has

$$\begin{aligned}
d_1^* &= \frac{(1 - n_1 + n_2)\,[1 - b_1 + n_2 (b_2 - b_1)]}{2 n_1 (1 + n_2)}, \\
E_1^* &= \frac{r\,[1 - (1 + n_2)\, b_1 + n_2 b_2]}{2q}, \\
E_2^* &= \frac{r n_2\,[1 - b_2 - (1 + n_2)(b_2 - b_1)]}{1q\,(1 + n_2)}, \\
x^* &= \frac{K\,[1 + (1 + n_2)\, b_1 + n_2 b_2]}{2\,(1 + n_2)}.
\end{aligned}$$

End of Proof.

In Case 1 of Proposition 1, note that the level of domestic effort taxation coincides with the domestically efficient level given in (15). Also, since the inequality defining Case 3 of Proposition 1 (foreign entry accommodation) can be written as

$$b_1 < b_2 < b_1 + \frac{1 - b_1}{2 + n_2},$$

it follows that, when $b_1 < b_2$, Cases 1 and 2 of Proposition 1 (foreign entry deterrence) will occur when n_2 is sufficiently large. Figures 1 and 2 illustrate how the set of effort cost combinations that lead to foreign entry deterrence increase as the number of firms in the foreign fleet goes from one to infinity.

Finally, note that whether the outcome of the game is also characterized by a domestic effort subsidy or a tax depends on domestic and foreign effort costs and the number of firms in both fleets. If $(1 + b_1)/2 < b_2$, then Case 1 of Proposition 1 occurs and the optimal domestic effort policy is the efficiency-inducing effort tax shown in (15), i.e., $d_1^* = \tilde{d}_1 \leq 0$, which does not depend on n_2. However, if the condition for Case 1 of Proposition 1 to occur is not satisfied, then the sign of the optimal domestic effort policy depends in a complex way on n_1 and n_2, as well as on b_1 and b_2. Defining

$$D = \frac{1 - b_2}{b_2 - b_1},$$

it can be determined that the outcome here involves a domestic effort subsidy, i.e., $d_1^* > 0$, if either $n_1 < D < 1 + n_2$ or $1 + n_2 < D$ and $1 + n_2 < n_1$. Alternatively, it will involve a domestic effort tax, i.e. $d_1^* < 0$, if either $n_1 < 1 + n_2 < D$ or $D < n_1$ and $D < 1 + n_2$. Thus any one of the four possible combinations of the domestic effort subsidy/tax and foreign entry deterrence/accommodation can occur when the domestic country has an effort cost advantage. The next section provides additional numerical verification of Proposition 1.

4.2.2 Numerical Simulation

In the numerical simulation below, parameter values similar to those given by Clark [1976], from Mohring's [1973] study of Pacific halibut, were used: $r = 0.71$ and $K = 80.5 \cdot 10^6$ kg. As noted by Dockner [1989], one may also, by taking suitable units of measurement for price and fishing effort, assume that $p = 1$ and $q = 1$. Also, for definiteness, we assume that $n_1 = n_2 = 1$. In order to show explicitly that each of the three cases outlined in Proposition 1 can occur, we next set $b_2 = 0.6$ and consider various possible values for the parameter b_1. We note that, although the values used are ad hoc, the range of parameter values does include $b = 0.23$, which corresponds to Mohring's estimate of the bioeconomic open-access equilibrium: $x_\infty = 1.75 \times 10^6$.

In the numerical simulation, then, when $b_1 = 0.1$, Case 1 of Proposition 1 occurs and the outcome is characterized by domestic efficiency ($d_1^* = 0$) and foreign entry deterrence. Thus the domestic effort cost advantage is so large that there is, in effect, no threat of foreign entry. When the domestic cost of effort is increased to $b_1 = 0.33$, Case 2 occurs and the outcome is again characterized by foreign entry deterrence, but this time accompanied by an inefficient domestic effort subsidy ($d_1^* = 0.133$). Finally, when the domestic cost of effort is increased again to $b_1 = 0.55$, Case 3 occurs and the outcome is characterized by foreign entry accommodation and an inefficient domestic effort subsidy ($d_1^* = 0.125$). These three cases are illustrated in Figure 3 using the mathematical interpretation of the first stage, in which domestic rent from the fishery is a piecewise quadratic function of the domestic effort policy.

4.2.3 Geometrical Interpretation

An alternative geometrical interpretation of the first stage may be obtained by graphing level curves of W_1 in the effort plane.[3] Shown in Figure 4 as parabolas for the three cases in the numerical simulation above, each level curve reveals the combinations of E_1 and E_2 among

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[3] This geometrical interpretation has been widely used in the strategic international trade policy literature. See Dixit [1987] and Mayer [1981] for examples of the use of level curves to interpret how countries choose tariff levels on imported goods.

which the domestic country is indifferent because they yield the same level of W_1. Since W_1 is higher along a level curve that has relatively more E_1 and relatively less E_2, higher levels of W_1 occur along level curves that are further down and to the right in the effort plane. Also shown in Figure 4 is the reaction curve of the foreign fleet, shown in (8), along which must lie the solution to the rent maximization problem for the domestic country in the first stage. Denoting this reaction curve by Γ_2, we note from (8) that Γ_2 is the union of a certain line segment ℓ_1 having negative slope, and a half infinite line segment ℓ_2 lying on the E_1 axis.

Using this geometrical interpretation, the domestic country wants to find the effort policy in the first stage that results in a combination of domestic and foreign effort levels in the second stage that: i) lies on the foreign reaction curve Γ_2, and ii) lies on the highest attainable level curve of W_1. The solution to this problem is determined as the point of tangency of this family of level curves of W_1 with the reaction curve Γ_2. In Case 1, which corresponds to domestic efficiency and foreign entry deterrence, the tangency point occurs on the line segment ℓ_2. In Case 2, which corresponds to domestic inefficiency and foreign entry deterrence, the tangency point occurs at the point where ℓ_1 and ℓ_2 meet. In Case 3, which corresponds to domestic inefficiency and foreign entry accommodation, the tangency point occurs on the line segment ℓ_1. These three cases, which use the same parameter values as those used in Figure 3, are illustrated in Figure 4.

4.2.4 Foreign Effort Cost Advantage

It is assumed here that $b_2 < b_1$, so that the foreign cost of effort in the fishery is less than the domestic cost of effort. As in Section 4.2.1, domestic rent from the fishery can be interpreted as a piecewise quadratic function of the domestic effort policy. Again, the graph of W_1 is obtained by concatenating together two parabolas having vertices given by (17) and (18).

Equation (20) shows that, regardless of n_1 and n_2, $\tilde{d}_1 < \beta$ and W_1 is monotonic decreasing on (β, ∞). Thus the maximum of W_1 occurs either at $\hat{d}_1$ or at one of the endpoints α or β. There are two cases to be considered. In the first case, $n_2 > (1 - b_1)/(b_1 - b_2)$ and a direct calculation shows that $\hat{d}_1 < \alpha$, so W_1 is monotonic decreasing (and negative) on (α, ∞), implying $d_1^* = \alpha$. In the second case, $n_2 \leq (1 - b_1)/(b_1 - b_2)$, and a direct calculation shows that $\alpha \leq d_1 < \beta$, so $d_1^* = \hat{d}_1$. In each of these cases, the corresponding d_1^* and (11) - (13) may be used to determine the subgame perfect equilibrium effort levels and the steady-state size of the fish stock. These results prove the following proposition.

Proposition 2 *In subgame perfect equilibrium, if the foreign country has an effort cost advantage over the domestic country, such that $b_2 < b_1$, then the outcome of the game can be characterized by one of two possibilities, depending on domestic and foreign effort costs and the number of firms in the foreign fleet:*

Case 1. If $n_2 > (1 - b_1)\,/\,(b_1 - b_2)$, then the outcome is characterized by domestic entry deterrence;

Case 2. If $n_2 \leq (1 - b_1)\,/\,(b_1 - b_2)$, then the outcome is characterized by domestic inefficiency and foreign entry accommodation.

It can also be verified that, in Case 1 of Proposition 2, the subgame perfect equilibrium has

$$\begin{aligned} d_1^* &= -\frac{1 - b_1 + n_2\,(b_2 - b_1)}{1 + n_2}, \\ E_1^* &= 0, \end{aligned}$$

$$
\begin{aligned}
E_2^* &= \frac{rn_2(1-b_2)}{q(1+n_2)}, \\
x^* &= \frac{K(1+n_2b_2)}{1+n_2},
\end{aligned}
$$

and in Case 2 of Proposition 2, the subgame perfect equilibrium has

$$d_1^* = \frac{(1-n_1+n_2)[1-b_1+n_2(b_2-b_1)]}{2n_1(1+n_2)}$$

and E_1^*, E_2^*, and x^* are as given in Case 2 of Proposition 1.

We note that, in Case 1 of Proposition 2, the solution has $E_1^* = W_1^* = 0$, so the optimal domestic effort policy in this case is any level that does not encourage domestic entry in the fishery. In particular, since $\alpha > 0$ in this case, the optimal domestic effort policy can be taken to be $d_1^* = 0$, i.e., neither effort subsidization nor taxation. In Case 2 of Proposition 2, the solution has positive levels of effort in the fishery by both fleets. Also, since $1-b_1+n_2(b_2-b_1) \geq 0$ in this case, the equation for d_1^* above may be used to show that the optimal domestic effort policy is an entry-accommodating effort subsidy if $n_1 < 1+n_2$ and an entry-accommodating effort tax if $n_1 > 1+n_2$.

5 Conclusion

This paper has shown that, in noncooperative transboundary fisheries, countries may have an incentive to provide effort subsidies to their domestic fleets in order to deter entry by rival foreign fleets. Even when entry deterrence does not occur, effort subsidies could still be provided in order to shift rent in these fisheries from foreign fleets to domestic fleets. In so doing, the paper helps to explain the persistence of subsidies in some, but not all, world fisheries. The paper does not provide an explanation for the persistence of subsides in domestic fisheries where there is no threat of foreign entry. With this in mind, the empirical implication of the paper is straightforward: other things being equal, countries will provide greater subsidies to those domestic fleets that face competition from foreign fleets than to those that do not.

Finally, it should be noted that the game analyzed here depends on the assumption that countries make credible commitments to policy actions on behalf of their fishing industries. For example, if the domestic country were to announce a reduced effort tax or an effort subsidy in the first stage, then effort in the fishery by the domestic fleet would only be greater in the second stage if it were understood that the domestic country is committed to a lower tax or a subsidy in the second stage. Once the reduced tax or subsidy is announced, the domestic country would prefer to renege on its commitment in the second stage (see Brander [1995] and Brander and Spencer [1985] for useful discussions of the commitment issue in the context of strategic trade policy).

FIGURE 1. Foreign entry accomodation and deterrence for $n_2 = 1$.

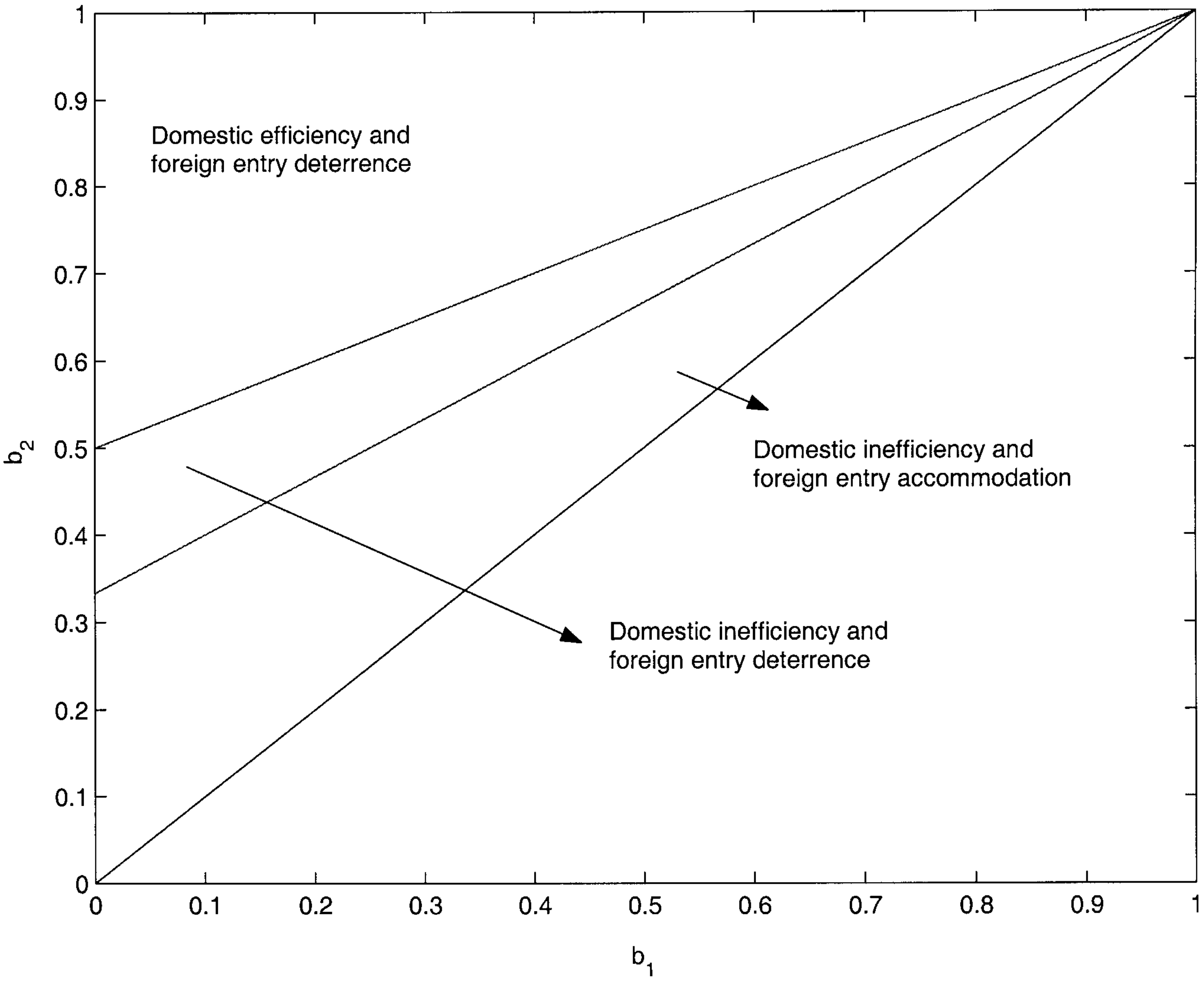


FIGURE 2: Foreign entry accomodation and deterrence for n_2 -> infinity

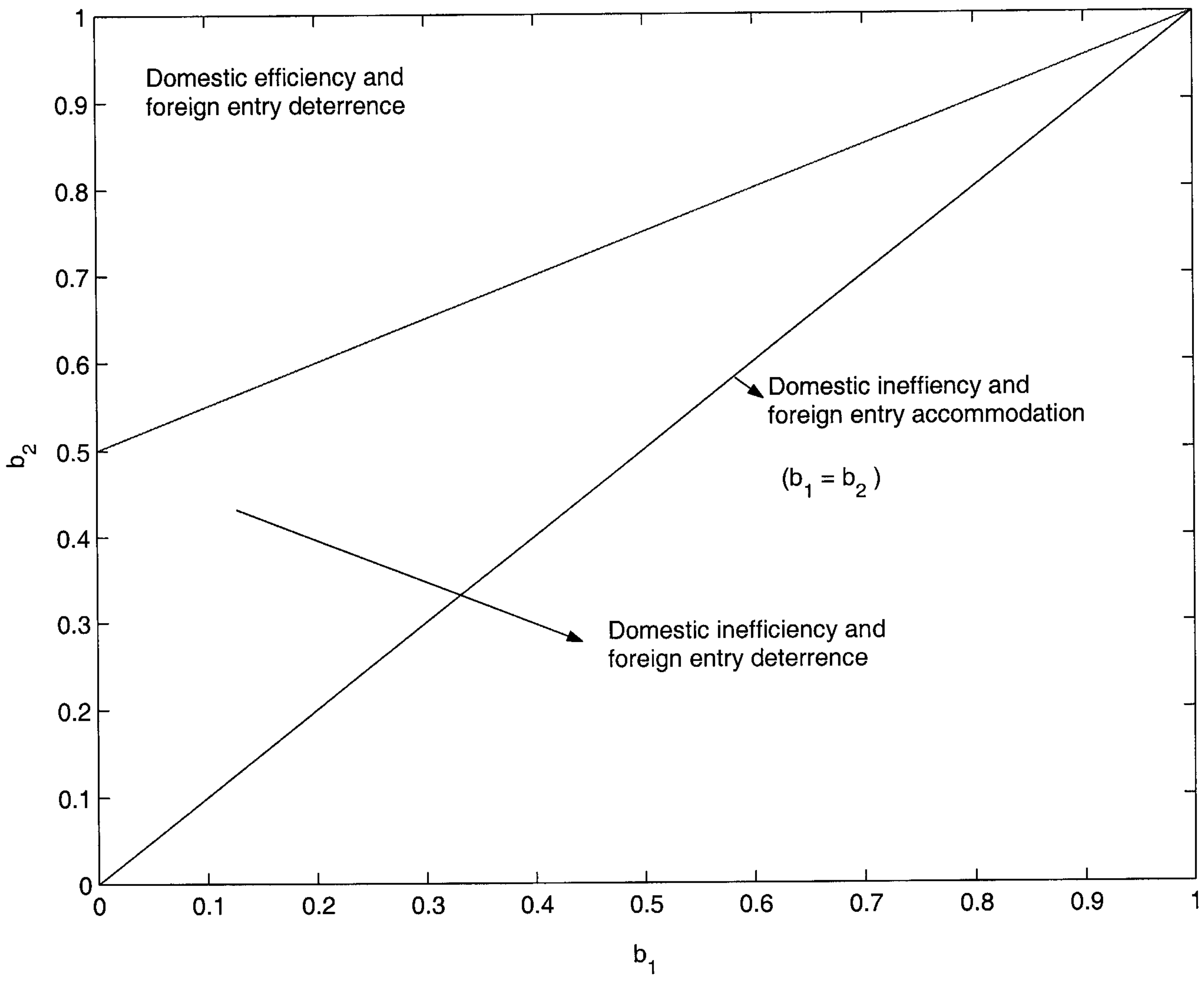


FIGURE 3: Determining the domestic effort policy in the numerical simulation

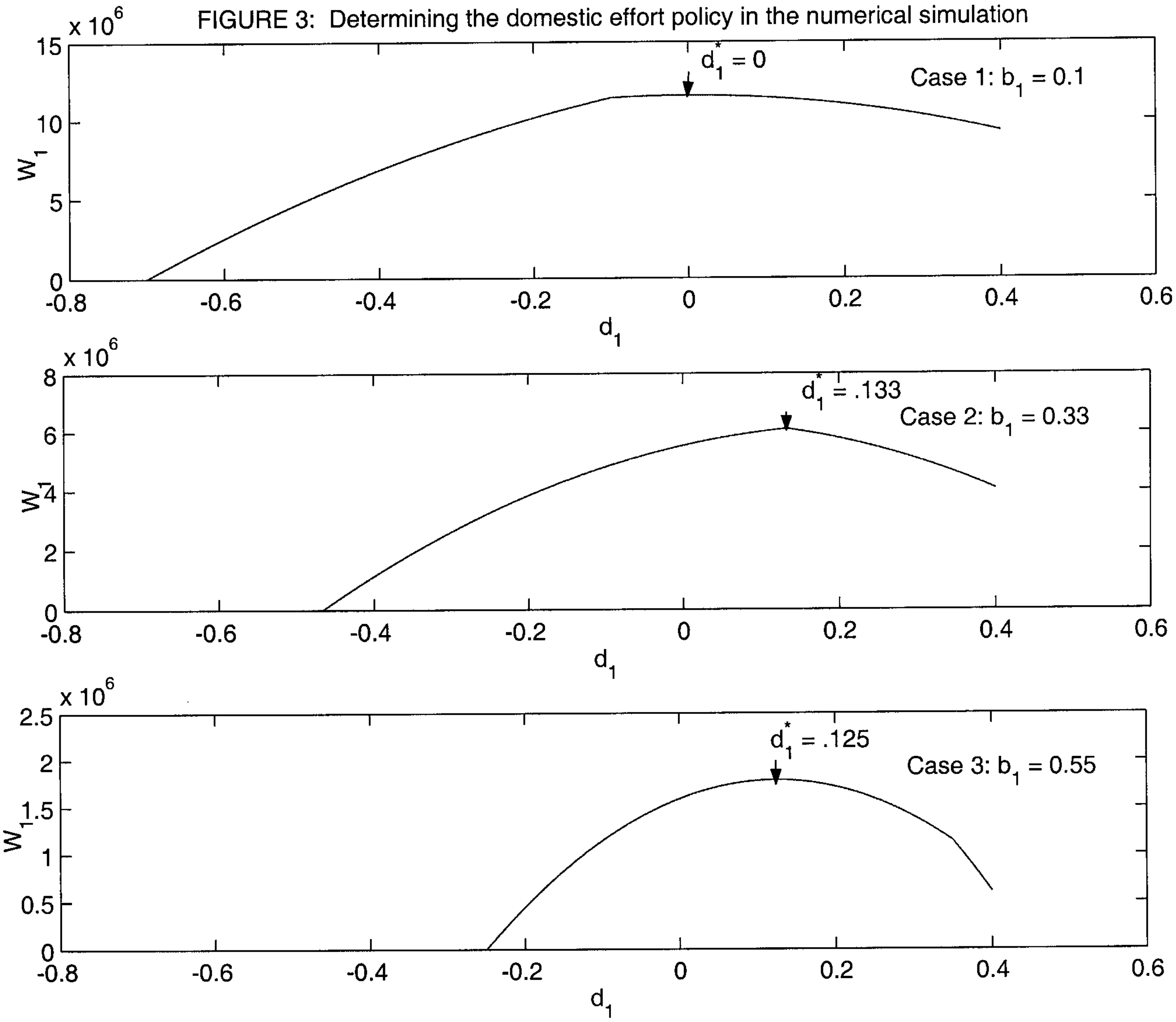
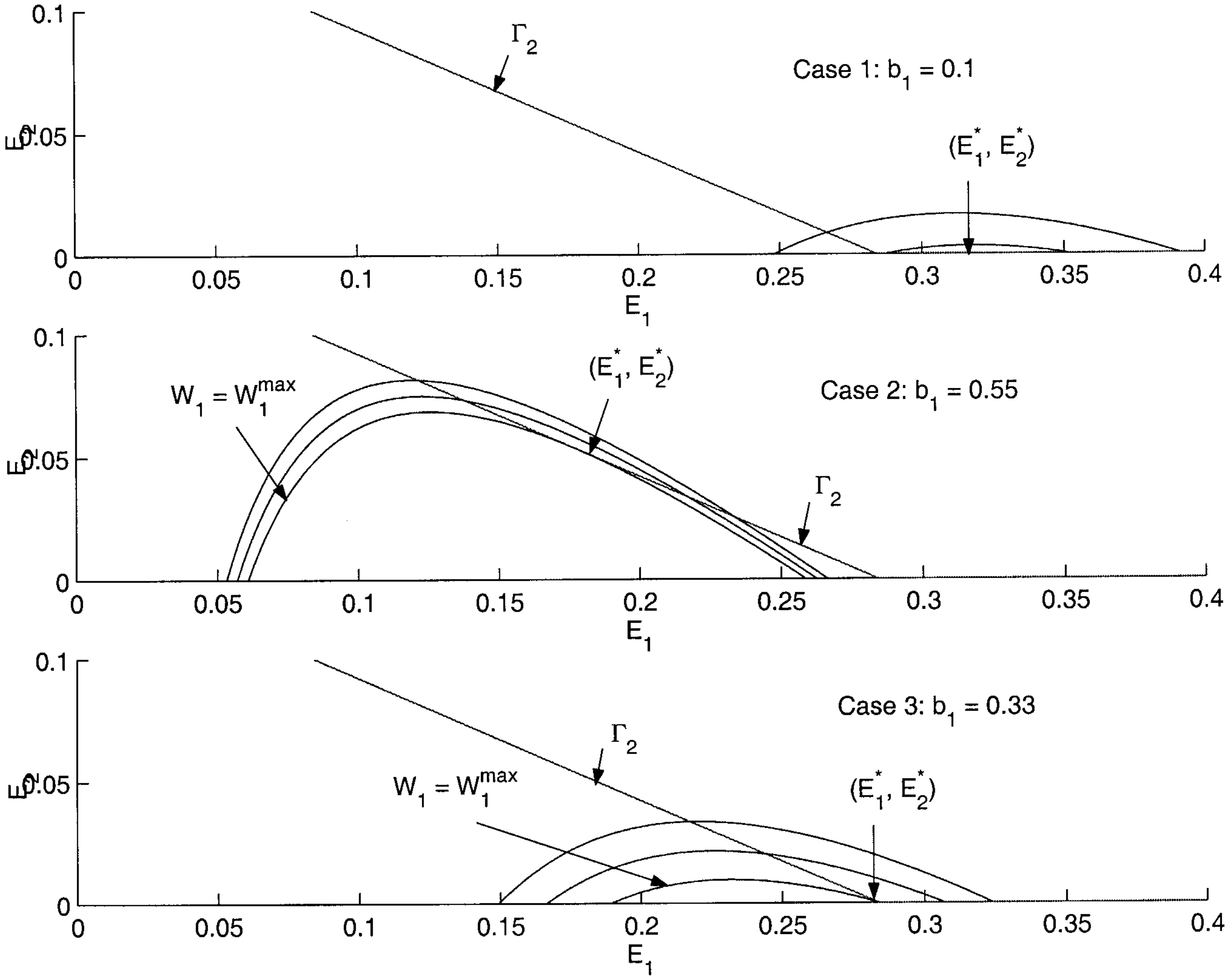


FIGURE 4. Level curves of domestic rent in the numerical simulation.



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