Environmental conflict and natural resources

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Abstract

With a constant flow of news stories linking conflict with the control of natural resources, one is led to believe that resource abundance fosters conflict. And yet, many would argue that natural resources can be used to support peaceful and stable growth. There is also much evidence that instead links resource scarcity with conflict. Over the past twenty years or so, the application of new theoretical modeling techniques, along with the availability of richer data sets on conflict, have contributed great strides in untangling those links. The challenge has been (and remains) to identify risk factors that make conflict more likely in the presence of resources. This chapter summarizes the main concepts and findings. We begin by highlighting the role of forceful appropriation as a means to acquire goods. A necessary parallel is then drawn between conflict economics and property-right economics. Two fundamental risk factors internal to natural resources are underscored: nonreplicability and appropriability. Examples of external risk factors, such as trade openness and institutions, is considered with the help of three simple models representative of the economic approach to micro and macro conflicts. The models also illustrate how resource use is in turn affected by conflict, or even its mere anticipation.

Keywords: Appropriation; Conflict economics; Environment; Expropriation; Free access; Natural resources; Nonreplicability; Property rights; Trade

1 Introduction

The presumption that the presence of natural resources can somehow be linked to the occurrence of conflicts goes back centuries. The proposed arguments, however, lead to much confusion as to the nature of the link. Here are but two representative examples.

Some authors will argue that conflict follows from resource degradation while others say just the opposite, i.e. resource abundance causes conflict. In some studies, the presence of conflict causes a resource to be over-exploited, while others make the case that conflict causes a resource to be left unexploited.

Though contradictory, the arguments presented above often reflect the observations made by their authors, and so none should be dismissed. Rather, the issue that they raise is that the link between conflict and natural resources is a complex one. It may be that depending on the context, not only can the sign of an effect may be reversed, but so can the direction of causation. In order to shed light on those questions, a number of theoretical models have begun to appear since the mid 1990's. The present survey is an attempt to summarize some of its main findings in light of the empirical work that has been done. Note that we are as much concerned about how the presence of natural resources causes conflict as how conflict can affect the management of resources.

The next section presents an overview of the economic approach to conflict. In section 3, I make the case that the economic analysis of conflict is very much an exercise in property rights economics. This is followed by section 4, where a basic theoretical approach is being proposed to help understand what makes natural resources different for explaining conflict occurrences. This is followed by three illustrative theoretical models of conflict and natural resource use.

2 What is conflict economics?

In economics, one typically finds that a good can be acquired through either production or exchange. In doing so, forceful appropriation is being ignored as a third important option. Broadly speaking, explicit consideration of this third option is the subject of conflict economics.

The acquisition of goods through exchange is usually understood as the outcome of a free choice between the exchanging parties. Exchange is free whenever all parties can exercise the option to withdraw from the exchange at no additional cost. This simple definition turns out to be crucial for conflict economics once it is matched with a definition of appropriation. There is appropriation when the following two conditions hold: (i) the control over a good or asset is being transferred between two parties; (ii) given the terms of the transfer, at least one of the two parties would not accept the transfer if it were free to do so.

The above two definitions imply that appropriation and exchange are exclusive: when A acquires a good from B, that good has either been freely exchanged or it has been appropriated. If walking out from a deal requires the assistance of a bodyguard, then the good being traded is subject to appropriation and trade is not entirely free. The terms of the trade will be affected by this and in anticipation, so are the production decisions.

Valuable goods always require some measure of protection, however small. Appropriation is therefore omnipresent and as a consequence, free exchange is just an approximation of a situation with negligible appropriation costs. It may therefore be said that conflict economics is that branch of economics which does not neglect appropriation costs as a means of acquiring a good or benefit.

Note that when considering the link between conflict and natural resources, we must adopt a broad view of conflict. Indeed, one naturally envisions conflict as a situation of open confrontation involving material destruction or violence. But agents will often base their actions precisely in order to avoid open confrontation. Hence, not only do those decisions help us understand the presence or absence of conflict, but they have an impact on the allocation of resources in the economy. The analysis of decisions taken in the *shadow of conflict* may be just as important as situations of open conflict for our understanding of the links between conflict and natural resource use.

Note further that as a sub-discipline of economics, conflict economics preserves the fundamental assumption that agents are (mostly) rational actors who make decisions in order to attain an objective, however defined, while taking into account their constraints. The tools of analysis being used are consequently no different.

3 Property rights and conflict

From a micro-economic perspective, the analysis of the relationship between conflict and natural resources or the environment is fundamentally an exercise in property right economics.[1] Such an approach informs our understanding of both micro conflicts, such as local conflict over land or water rights, and macro conflicts, such as civil wars and interstate wars.

One common view in the Law and Economics literature holds that a property right must be viewed as the ability to derive a benefit from a resource. One way or another, this ability depends on the amount of control one has over the resource. Resource control is therefore a fundamental concept to define. To see why, let us take the case of a fishing ground.

My control over a fishing ground may be conceived as my ability to decide on the use of the resource, such as who can access the ground, for how long and with what type of gear. This requires my ability to exclude unwanted

[1] On additional issues of property rights, see chapters 104 by Duke and 141 by Cherry.

users and non-compliers. Indeed, without such exclusion, my ability to derive benefits will likely be eroded away by others.

But the ability to exclude is not sufficient. Indeed, excluding others will not bring me benefits if others can also exclude me and those to whom I wish to allow access. This suggests that a property right over a resource depends on both the ability not to be excluded from using the resource and the ability to exclude others from using the resource. Exclusion is therefore an essential feature of a property right. And this is where property right and conflict analysis become closely intertwined.

For a natural resource that is scarce and valuable, the property right holder must expend efforts in order to exclude unwanted users from appropriating it. In return, unwanted users may be willing to expend efforts in order to access a valuable resource. The nature and intensity of those efforts will depend on a host of factors, such as the value of the resource, the laws, norms, and customs of a society, the state's support for property rights, the technology of resource extraction, the technology and cost of private exclusion efforts, grievances in the face of a perceived injustice, etc. Sometimes, those factors combine in such a way that people see the use of destruction and violence as justified or profitable options. Uncovering the role played by those factors is one main object of conflict economics.

It should be clear by now that if the acquisition of a valuable resource requires exclusion or access efforts, then the resource is obtained through appropriation. As discussed in section 2, this corresponds to the third manner with which one can acquire a benefit, other than through exchange or production. For this reason, we shall henceforth speak of appropriation efforts to refer to either exclusion or access efforts.

4 What makes natural resources so special in relation to conflict?

There is a presumption that natural resource abundance can be a curse because it increases the risk of conflict. Anecdotal evidence that feeds such beliefs is certainly not lacking: just think of stories of civil war and repression in oil producing countries, forceful eviction of peasants from their land in the Brazilian amazonian forest, confrontation between gold diggers in the 1848 California Gold Rush, or communities revolting against the local activities of big international mining firms.

More systematic empirical work, however, suggests caution as resource abundance does not always increase the risk of conflict. Rather, the risk is contingent on a host of proximate factors such as resource type, conflict type, countries and time. Given this, attempts have been made to identify some fundamental characteristics of resource types that make them more or less prone to conflict. Is there something common to such varied resources as an underground oil reservoir, a gold deposit, an oyster bed and a tropical forest that explains conflicting outcomes? Another challenge has been to identify environmental variables, both institutional and economic, that vary across time and place and may interact with the presence of resources in order to produce peaceful or conflict outcomes.

There are many mechanisms that have been proposed in the recent literature. They essentially rest on two pillar concepts: *nonreplicability* and *appropriability*.

4.1 Nonreplicability

A natural resource must be conceived as one input among many that are necessary for the production of some good, intermediate or final. To illustrate, the production of oil may be said to require three different input types: labor, capital and an underground oil deposit. Production of wheat also requires labor and capital, but must be combined with a plot of land as a third input type.

The oil producing firm can adjust at will the amount of labor and capital used for extraction. The size of the oil deposit, however, is fixed by nature. The same holds for a plot of land of a given grade and located at a given distance from the market. For this reason, the natural resource is termed a fixed factor of production while labor and capital are variable factors. This is conveniently represented by the following output function:

$$y = f(\mathbf{x}, S), \quad \mathbf{x} = (x_1, x_2, ..., x_n), \tag{1}$$

where $\mathbf{x}$ is a vector of n variable factors and S is the fixed input that is the natural resource. (Note that we abstract from resource dynamic considerations to simplify the discussion. This does not affect the essence of the argument made here.)

The presence of a fixed factor implies that the production technology exhibits decreasing returns to the variable factors. Just think of an ever increasing number of variable factors as they crowd up over a single resource site. Equally important is the reason why the factor is fixed: the natural resource input is of fixed size because of its nonreplicability. Indeed, it is not possible to replicate the use of a gold deposit as an input, be it on the site itself (*in situ*) or anywhere else (*ex situ*). The same holds for the highly fertile plot of land or the oil field with a low cost of extraction. Nonreplicability implies that entry is not free into the respective industry, even in the long run.

Now there is a well known result in economics to the effect that the combination of decreasing returns and nonreplicability is consistent with strictly positive profits. A full demonstration is not warranted here. But since the implications are so fundamental to our understanding of resource abundance and conflict, the following simple counterexample will take us far.

Take the milk delivery business. It requires a truck, fuel and labor as inputs. All those inputs can be bought on the market so that the business of milk delivery is easily replicable. Suppose then that the demand for milk delivery services suddenly jumps this year, providing existing milk deliverers with revenues that well exceed their costs. Others will be drawn into the business through the hiring of the variable inputs. The *ex situ* replication of milk delivery activities insures that the business will not generate above-normal profits for very long. And most importantly, above-normal profits have been dissipated through the "peaceful" process of replication.

In the case of a natural resource, above-normal profits are called rents because they originate from the nonreplicability of the resource. The level of the rents on a site is dependent on a host of factors. Since resource rents affect the risk of conflict, it is important to identify what those factors are. Assume, for simplicity, that there is only one variable factor x. The rents are given by

$$R = pf(x, S) - cx, \tag{2}$$

where c is the unit cost of the variable input and p is the unit price of the output. R is often said to represent the returns to the fixed factor S. Not surprisingly, the magnitude of the rents depends on the output price p and input cost c. But it also depends on the productivity of the variable factor x, which in turn depends on the size and quality of the fixed factor S, the shape of the production technology f, as well as the quantity of x being put to use. Each of those factors has a role to play in understanding conflict.

In the milk delivery example above, we have said that whenever an opportunity for rents existed, outsiders would be drawn into the business. In that case, rents are dissipated through *ex situ* replication. In the case of a nonreplicable input, the fact that *ex situ* replication is not an option does not mean that outsiders will relinquish on a good opportunity to collect rents. This is where the problem of resource appropriability arises.

4.2 Appropriability

In the previous section, we have discussed why natural resources can produce rents. But this only reflects a potential for rent generation; it does not mean that it will be attained in practice. Appropriability difficulties can be a serious impediment. In what follows, we explain why the appropriability properties of a resource site governs the degree to which it will actually fulfil its rent generation potential. In doing so, we provide a direct link to the conflict proneness of a resource.

When *ex-situ* replication is not possible, people may still look for other ways to benefit from the activity through some form of rent appropriation. This often leads to conflict. In the case of natural resources, the nature of the conflict typically falls within one of the following four major forms of appropriation:

i) **Expropriation** When control of the resource site is obtained through forceful eviction of the present users.

ii) **Input access** When "outsiders" attempt to access the resource with their own input efforts to be used alongside those of the present users.

iii) **Theft** When the output is stolen before it reaches market.

iv) **Extortion** When one of the rent collectors, often a local government, is forced to return some of the rents through the threat of violence.

To grasp the implications of the different forms of appropriation, we present three models of conflict and natural resource use related to expropriation and input access. The models are intended to be illustrative of the different forms of appropriation and their impact on conflict and resource use.

5 Expropriation and conflict

In the framework of production function (1), expropriation refers to a situation where the parties to the conflict are each trying to exploit the resource with their own variable inputs while completely excluding the other party's variable inputs. For instance, the fixed input S may be a plot of land located in a frontier region where property rights are not clearly defined. A contestant may then try to forcefully dislodge the occupant in order to exploit the land with his own tools and labor force. Alternatively, S may be an underground ore deposit being exploited by a state agency. A rebel group then tries to expel the state agency's users from accessing the deposit in order to replace them.

5.1 The game

For concreteness, let us take the case of a frontier region that is located so far away from a country's administrative centers that it is practically impossible to stake a property claim with the assistance of the state. The resource being contested is a plot of land which may be used sustainably or not.

A plot of land can be used to produce a harvest now and into the indefinite future. Let $y(t)$ denote the harvest at period t, with $t \in \{0, 1, 2, 3, ...\}$. We consider a simplified dynamic setting in which the present and the future are collapsed into two relevant periods only: period 0 and period 1.[2] All decisions are taken during period 0, so that the future is completely determined by period 1 onward. In particular, the land's productivity in each period depends on the choice made by its user at time 0. This choice of use is binary: the user opts for either a sustainable use or a non-sustainable use. A sustainable use produces a constant per-period output level y_s, i.e. $y(t) = y_s$ for $t \in \{0, 1, 2, 3, ...\}$. A non-sustainable use initially yields a higher output level $y(0) = y_m > y_s$, but leaves the land totally unproductive for the future, i.e. $y(t) = 0$ for $t \in \{1, 2, 3, ...\}$; for this reason, it is referred to as land mining. A unit of harvest can be sold at price p, which is constant through time. Sustainable use therefore produces a benefit of py_s in each period. Land mining yields benefit py_m at period 0 only. To simplify, land use is assumed to be costless.

The game tree is illustrated in figure 1. There are two players involved: a first settler (player A) and a contestant (player B). Player A is the first to occupy and use a specific plot of land. We assume that the land was previously unowned and unused. What has attracted the first settler to this plot of land in the first place is exogenous to the analysis. It could be explained by frontier development resulting from a combination of population

[2]See chapter 148 by van Long for models of resource use with multi-period interactions.

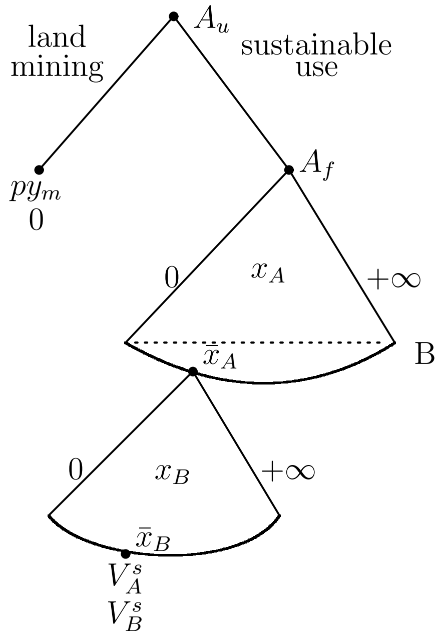

Figure 1: A game of expropriation, land mining and conflict

growth, the completion of a new road, and higher output prices in world markets. At the beginning of period 0, player A decides on the type of land use, at per node A_u in the game tree. This decision is irreversible and is perfectly observable by both players. Player A reaps the benefits of period 0's output with certainty but faces a probability of being evicted by the time period 1 begins. Once evicted, he receives no more benefit from the land's output. Player A may however affect the probability of an eviction by resisting against the contestant with fighting – or appropriation – effort x_A, which can take on any real value between 0 and $+\infty$, as represented by node A_f in the game tree.

Player B decides on the level of efforts in her attempts to evict player A from the plot of land. A successful eviction provides player B with uncontested access to the future benefits from the land. Player B's appropriation efforts are denoted x_B, which also takes on any real value between 0 and $+\infty$, as illustrated by the last branches of the game tree. The dotted line represents the fact that player B chooses x_B before observing x_A, as it is assumed to be a simultaneous choice. In figure 1, choice pair $(\bar{x}_A, \bar{x}_B)$ provides one possible combination of fighting efforts which yields the respective payoffs (V_A^s, V_B^s), with values to be determined below.

Note that there are two decision stages to this game, but that both are taken during period 0. First, player A decides on the type of land use. If he opts to mine the land, the game ends there and the players' payoffs are py_m and 0 for A and B respectively. If he chooses a sustainable use, the players enter into a conflict by simultaneously deciding on their fighting efforts. Those appropriation efforts have a unit cost of 1 and are fully incurred during period 0.

Player A always reaps the present harvest in period 0. In the case of a sustainable use, whether it is player A or player B that reaps the future harvests hinges on the outcome of the conflict. If player B wins, player A is evicted at the end of period 0 and player B keeps the land and its future harvests. Otherwise, player A stays on the land. Assuming a discount rate $r > 0$, the present value of a sustainable use from period 1 onward is given by $V_1^s = \sum_{t=1}^{\infty}(1/(1+r))^{t-1} py_s = (1+1/r)py_s$.

The probability that player A is successful at avoiding eviction is given by the following function:

$$\pi(x_A, x_B) = \frac{x_A}{x_A + x_B}. \tag{3}$$

$\pi(x_A, x_B)$ is a function that "transforms" fighting efforts into probabilities of winning and losing the conflict. It reflects the technology of conflict. In the literature on the economic analysis of conflict, this type of function is called a *contest success function* (CSF).[3] A CSF can take on many different forms with varying properties; the one proposed in (3) is referred to as a *ratio-form* CSF because the probability of eviction depends solely on the ratio of appropriation efforts x_A/x_B. As would be expected, the probability of a successful eviction decreases with x_A and increases with x_B; it is equal to $1 - \pi = x_B/(x_A + x_B)$.

Assuming that both players are risk neutral, the expected payoff at period 0 from a sustainable use of the land, given x_A and x_B, is equal to the following

[3] See chapter 19 by Heyes and Heyes for similar models of "peaceful" contests that shape environmental policy.

two expressions for players A and B respectively:

$$V_A^s = py_s + \pi(x_A, x_B)\frac{V_1^s}{1+r} - x_A, \tag{4}$$

$$V_B^s = (1 - \pi(x_A, x_B))\frac{V_1^s}{1+r} - x_B. \tag{5}$$

If player A rather opts to mine the land, then the respective payoffs are $V_A^m = py_m$ and $V_B^m = 0$.

Note that we assume that in a (utopian) world of perfectly and costlessly enforced property rights, a sustainable use has more value than land mining, despite the fact that land mining may bring a short term gain, i.e. $py_s < py_m < (1+1/r)py_s$. Whether player A opts for a sustainable use or not hinges on a comparison of the *equilibrium* value for V_A^s with V_A^m. Resolving the game backward, we begin with a characterization of the conflict equilibrium in the case of a sustainable use.

5.2 The sustainable-use-cum-conflict equilibrium

In order to characterize the Nash equilibrium choice of appropriation efforts, we begin by deriving each player's *reaction function*. In the case of player A, this function determines the choice of appropriation effort x_A that maximizes V_A^s for any *given* level of appropriation effort x_B exerted by player B. We have the following first-order condition:

$$\frac{\partial V_A^s}{\partial x_A} = \frac{\partial \pi(x_A, x_B)}{\partial x_A}\frac{V_1^s}{1+r} - 1 = 0. \tag{6}$$

This yields the following reaction function for player A:

$$x_A(x_B) = \sqrt{\frac{x_B V_1^s}{1+r}} - x_B. \tag{7}$$

Analogously for player B, we have $x_B(x_A) = \sqrt{x_A V_1^s/(1+r)} - x_A$.

The Nash equilibrium lies at the intersection of both reaction functions, as illustrated by point NE in figure 2. This yields the following equilibrium appropriation efforts by each player:

$$x_A^e = x_B^e = \frac{V_1^s}{4(1+r)}. \tag{8}$$

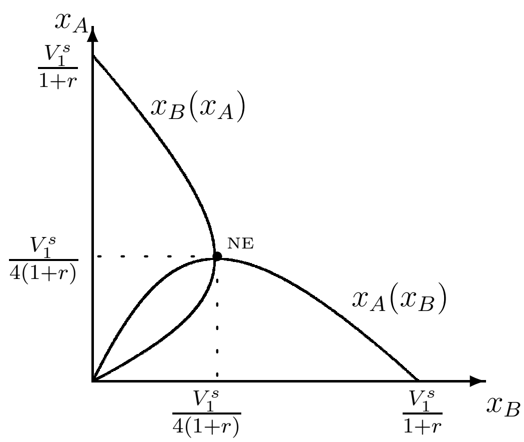

Figure 2: Reaction functions and conflict with sustainable use

Both players expend the same amount of appropriation effort in this game, such that in equilibrium, an eviction will occur with probability one half. This is due to the assumed conflict's symmetry between the players. In the case of a sustainable use, the prize to be won has the same value V_1^s for both, they both discount future gains at the same rate, and the shape of the CSF is characterized by a symmetry between each player's appropriation efforts. Of course, in many situations of conflict, such symmetry may not hold. For instance, one may want to differentiate between defensive and offensive efforts, or between the fact that one player's property rights have the state's partial backing. There are models that allow for such asymmetries. For now, however, assuming symmetry allows for a convenient and simple way to look at the interactions between conflict and resource use.

We define *conflict intensity* as the total amount of appropriation efforts $x_A^e + x_B^e$. The equilibrium identified in (8) predicts a conflict intensity of magnitude $V_1^s/2(1+r)$, or one half of the present value of the prize being sought. This value corresponds to a direct social loss from conflict in terms of efforts being diverted away from productive use. Indeed, fighting efforts x_A and x_B may be considered non-productive activities in the sense that they only seek to appropriate a pre-existing resource instead of creating new wealth. (This argument assumes that the unit cost of fighting effort corresponds to its true social opportunity cost.)

Naturally, we obtain that conflict intensity increases with both the productivity y_s of the resource and its value p. What deserves explanation is the positive impact of a lower discount rate. For each player, fighting constitutes an investment made today in order to secure a future gain (a feature which can be generalized to many situations of conflict). For a fixed value of the future gain, a lower discount rate increases the discounted value of the prize to be won, thus inducing more intensive fighting. But there is a compounding effect, which is that the value of the prize to be won increases with a lower discount rate as it incorporates the value of the harvest that will occur after period 1. Note, however, that those increased equilibrium efforts go to pure waste as the equilibrium probability of an eviction remains equal to one half.

Inserting equilibrium appropriation effort values x_A^e and x_B^e back into value function (4), we obtain the following expected equilibrium value for player A in the case of a sustainable use:

$$V_A^{se} = \left(1 + \frac{1}{4r}\right) p y_s. \tag{9}$$

Compared to a potential social benefit of $(1 + 1/r)py_s$, the presence of conflict deducts $(3/4r)py_s$ from the value of a sustainable use for player A, who may also decide on a different type of use. This deduction can be broken down into two parts: one is the reduction in the probability of receiving the future benefits of a sustainable use, which dropped from 1 to 1/2; the other is the addition of appropriation costs $V_1^s/4(1+r)$. In his decision to use the resource, the first settler will account for those additional costs, a question to which we now turn.

5.3 The resource use decision

As far as player A is concerned, equilibrium value V_A^{se} represents the relevant private expected benefit from a sustainable use that must be compared to the value of land mining. If it so happens that $(1 + 1/4r)py_s < py_m$, player A will opt to mine the resource, seeking to secure the short-term gain that resource mining procures over the higher long-term value of a sustainable use that is both uncertain and requires appropriation expenditures.

An important implication of the above result is that peaceful outcomes should not be confused with situations where property right issues have been resolved. Indeed, decisions made in the *shadow of conflict* may result in peaceful outcomes because users have decided to deplete the resource, thus leaving little to fight for. Which of the two situations is more desirable from society's point of view is not immediately obvious, as discussed in the next section.

5.4 A note on the efficiency of private decisions to engage into conflict

We assume that the only social cost of open confrontation consists in the sum of appropriations efforts; there is therefore no destruction. The social value of a sustainable use of the resource is then given by

$$W_s^e = py_s + \frac{V_1^s}{1+r} - x_A^e - x_B^e. \tag{10}$$

From an efficiency standpoint, W_s^e is the value that must be compared to the value of resource mining in order to determine which of the two resource uses is preferable. Accounting for the conflict that it entails, we obtain that the social value of a sustainable use is equal to $W_s^e = (1 + 1/2r)py_s$, which is larger than player A's value in (9). Consequently, the private decision to mine the resource will be inefficient in cases where $(1 + 1/4r)py_s < py_m < (1 + /2r)py_s$. Put differently, there may not be enough conflict! To see why, one must look at the discrepancy between the private and social costs of conflict, which has two sources.

First is the fact that although the appropriation efforts of player B are included in the social cost of conflict, player A does not account for them. This tends to make the private cost of conflict *lower* than the social cost. The second discrepancy is due to the fact that an eviction probability lowers the value of the resource to player A, but it does not count as a social loss because it merely represents a wealth transfer between the players. This tends to make the private cost of conflict *higher* than the social cost.

We therefore have two sources of discrepancies between the private and social costs of conflict that oppose each other. In the above example, it so turns out that the first effect is smaller than the second, thus making the private loss from conflict to player A larger than the social one. Although the sign of the net effect may not always be the same, the sources of the discrepancies will hold as a general principle.

6 Input access and conflict

Contrary to the case of expropriation, under input access types of conflicts, outsiders are not aiming to expel the present users. They rather attempt to share in the use of the fixed factor by bringing their own variable inputs. Due to the decreasing returns of the variable factors, this may not be welcome by the present users. To gain insight, we must begin with the following simple two-user, free-access problem.[4]

6.1 Harvesting a resource under free access

For concreteness, take an oyster bed as the fixed input S. Two harvesters can freely access the oyster bed with their boats, i.e. there is no restriction being imposed in any manner. The only variable input x is the amount of effort spent harvesting, as per expression (2). $f(x, S)$ denotes the total kilograms of oysters harvested, c is the opportunity cost of harvesting effort, and one kilogram fetches a constant unit price p. Since S is fixed throughout, we simply represent the total output by $y = f(x)$, with $f' > 0$ and $f'' < 0$.

The harvesters are identically productive. Therefore, letting $\phi(x)$ denote the average product of harvest effort, i.e. $\phi(x) \equiv f(x)/x$, the share of total output received by harvester i is given by $y_i = x_i\phi(x)$, where x_i is the effort chosen by harvester i, $i \in \{1, 2\}$, and $x = x_1 + x_2$.

We wish to identify a non-cooperative equilibrium. This is appropriate because, as will be seen below, cooperation demands that restrictions be imposed, thus violating the free access assumption. In this respect, the Nash equilibrium constitutes a simple, insightful equilibrium concept. We derive harvester 1's reaction function $x_1(x_2)$ by solving for the following problem, for given x_2:

$$\max_{x_1} R_1 = x_1 p\phi(x) - cx_1 \text{ where } x = x_1 + x_2. \tag{11}$$

The first-order condition for an interior solution yields the following implicit relation between x_1 and x_2:

$$\frac{\partial R_1}{\partial x_1} = p\phi(x_1 + x_2) + x_1 p\phi'(x_1 + x_2) - c = 0. \tag{12}$$

For harvester 1, adding a (marginal) effort increases his revenue by its average product $p\phi(x)$, at the cost of a lower average productivity $p\phi'(x) < 0$ that affects all of his efforts x_1, in addition to a direct unit cost c. The source of a potential conflict between the harvesters can already be seen from condition

[4] See chapter 45 by Wilen on restricting entry to resources and chapter 114 by Sanchirico on the problem of open access to natural resources.

(12): the negative productivity effect produces a loss of $x_2 p\phi'(x)$ to harvester 2 but is unaccounted for by player 1.

The reaction function $x_2(x_1)$ of harvester 2 is derived analogously. Through implicit differentiation, it can be verified that the reaction functions are negatively sloped, as illustrated in figure 3. x^* denotes the rent maximizing effort level, i.e. $pf'(x^*) = c$, while x^∞ corresponds to the effort level that dissipates all rents, i.e. $p\phi(x^\infty) = c$. The non-cooperative equilibrium is at point FA, where both reaction curves meet. The dotted lines x^*x^* and $x^\infty x^\infty$ are iso-input lines along which rents are respectively maximized and zero.

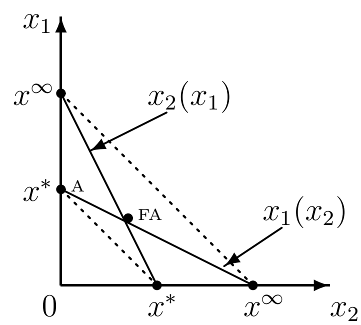

Figure 3: The harvesters' reaction functions and the free-access equilibrium

Point FA being located above line x^*x^*, the resource is over-exploited in the non-cooperative equilibrium and rents are not maximized. This equilibrium corresponds to total input level x^{FA} in figure 4 which depicts the average and marginal product value curves. Note that the free access equilibrium lies below line $x^\infty x^\infty$, which means that rents are not completely dissipated in the free access equilibrium. (If we had assumed an arbitrarily large number of harvesters rather than just two, then the free access equilibrium would coincide with a total input effort x^∞ and complete rent dissipation. This result will be used in the model of section 7.)

In order to increase their combined rents, the harvesters could of course always agree on an input restriction rule such that their total effort drops to x^*, i.e. somewhere along line x^*x^* in figure 3. Such a solution, however, is too simplistic as it ignores the presence of transaction costs. Indeed, input restrictions in practice raises many issues of enforcement that aim to *i)* insure that members of the group respect the restriction rules and *ii)* impede entry

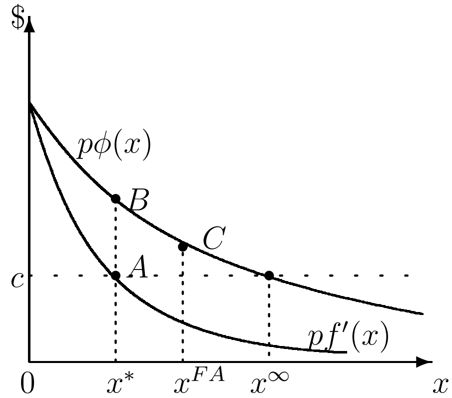

Figure 4: Input exclusion and conflict

by outsiders. Both enforcement issues have the same origin: as input use is being restricted from x^{FA} to x^*, the average product of the inputs increases, as can be seen by comparing points B and C in figure 4. This raises the gap between the average product value and the unit cost of an input, thereby increasing the return from breaking the rule for group members, or trespassing on the resource for outsiders. This may result in a confrontation with the enforcers, a question to which we now turn.

6.2 Restricted access and conflict

To illustrate the possibility of confrontation in the context of input access, along with its implications on resource use, let us consider the following situation. Free access is removed by making harvester 1 legally legitimate while turning harvester 2 into a potential poacher.[5] Note that harvester 1 could equally be a single firm or a group of users from a community that agree on restricted use, and similarly for the poacher. Legitimacy is assumed here for convenience. Either way, enforcement activities against poaching must be undertaken and are referred to as policing activities, which include monitoring and eventual forceful apprehension. Policing efforts are subsumed by probability $\gamma \in (0, 1)$ of apprehending the poacher.

A poacher can take all sorts of measures to avoid being caught by the

[5] See also chapter 117 by Skonhoft on poaching issues

police, going from detection avoidance to violently resisting arrest. This implies that for a total effort level x_2 exerted by the poacher, his *effective* harvesting effort e_2 is lower. Given that a larger γ corresponds to heavier enforcement by the police, the poacher is induced to take more avoidance measures, thus reducing further the effectiveness of his harvesting efforts. In order to capture this effect, we assume that $e_2 = (1-\gamma)x_2$, which implies that for a true poaching effort x_2, a share γx_2 is devoted to apprehension avoidance, the balance being used for actual harvesting.

For harvester 1, true and effective effort is the same since he does not have to engage in avoidance activities. Consequently, if x denotes the *effective* total harvesting effort on the oyster bed, we have $x = x_1 + e_2$. As was the case for free access, the respective harvest levels are given by $x_1\phi(x)$ and $e_2\phi(x)$. To simplify the problem, we assume that the policing level γ is fixed.

Through substitution, we have that the total harvesting cost of the poacher in terms of effective effort is $cx_2 = ce_2/(1-\gamma)$. The problem of the poacher can thus be expressed as follows:

$$\max_{e_2} \pi_2 = e_2\phi(x) - \frac{c}{1-\gamma}e_2 \text{ where } x = x_1 + e_2. \tag{13}$$

The poacher's reaction function to x_1 and γ is given by the following first-order condition:

$$\frac{\partial \pi_2}{\partial e_2} = \phi(x) + e_2\phi'(x) - \frac{c}{1-\gamma} = 0. \tag{14}$$

A comparison with expression (12) in the free-access case indicates that policing discourages poaching through an increase in the unit cost of effective effort. Assuming from now on that $f(x) = 10x - x^2$ and $c = 1$, we obtain the following reaction function:

$$e_2 = 5 - \frac{1}{2(1-\gamma)} - \frac{x_1}{2}. \tag{15}$$

According to this expression, the effective poaching effort decreases with both the policing effort γ and the harvesting effort of the legitimate user x_1, as depicted in figure 5 with two reaction functions for the poacher, one representing free access ($\gamma = 0$), the other with some policing ($\gamma = 0.5$).

Solving now for a (Stackelberg type) sequential game in which the legitimate harvester gets to choose x_1 first and then the poacher chooses e_2

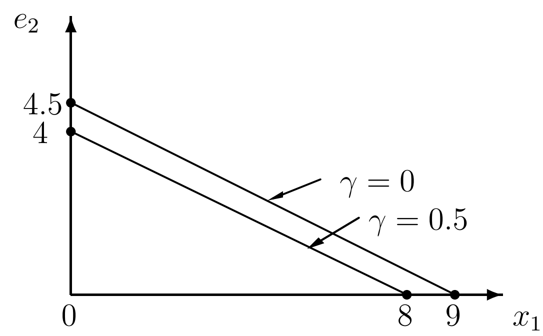

Figure 5: A poacher's response to policing

after observing x_1, given the policing effort γ, the problem of the legitimate harvester is expressed as follows:

$$\max_{x_1, e_2} \pi_1 = x_1\phi(x) - cx_1, \tag{16}$$

$$\text{s.t.} \quad e_2 = 5 - \frac{1}{2(1-\gamma)} - \frac{x_1}{2}, \tag{17}$$

$$\text{and} \quad x = x_1 + e_2. \tag{18}$$

In an interior solution, this problem yields the following equilibrium input quantities:

$$x_1^o = 4 + \frac{1}{2(1-\gamma)}, \tag{19}$$

$$e_2^o = 3 - \frac{3}{4(1-\gamma)}. \tag{20}$$

Despite the fact that the policing effort has not been made a choice variable in the legitimate harvesters problem in (16), as should be the case in a full-fledged model, the sequential equilibrium values x_1^o and e_2^o already provide much insight into the conflict situation.

We first observe that poaching is completely deterred in equilibrium when policing efforts amount to $\gamma = 0.75$. Deterrence, however, is obtained at the cost of some over-exploitation of the resource since $x_1^o = 6$, a value which is larger than the rent maximizing value $x^* = 4.5$ obtained from $pf'(x^*) = c$. This suggests that conflict may be avoided with intentional resource over-exploitation.

A second implication is that in an interior solution, an increase in policing will achieve its objective of mitigating resource overuse by reducing both input uses x_1^o and e_2^o. It may, however, end up creating more confrontation since a higher γ has an ambiguous impact on the poacher's equilibrium avoidance effort which is given by $\gamma x_2^o = (\gamma/(1-\gamma))e_2^o$. Whether this is the case or not will depend on a host of factors, as we discuss next.

6.3 Discussion and extensions

As discussed in section 4, the presence and intensity of the conflict will depend on the various parameters of the problem. Regarding its appropriability, the physical setting of the resource plays a fundamental role. For instance, it may seem pointless to try to exclude people from collecting firewood in a forest that spans a large surface located around a poor, densely populated urban area. This results in a *de facto* free access, an absence of conflict, and a resource that is severely over-exploited. Introducing a stock-flow resource dynamic to the problem will likely predict its total depletion.

Conversely, in the case of an inshore fishery well circumscribed into a small bay area, a local group of users may organize to exclude others with a reasonable chance of success. The resource will thus be better managed as a result, though confrontations between excluders and poachers may occur at times, the frequency of which will depend partly on the density of the surrounding population, as well as its alternative income opportunities. It has been reported, for instance, that confrontations can be significantly dependent on the business cycle as it affects the incentives by both poachers and excluders.

Another factor that affects the shape of the conflict is the type of variable input necessary to exploit the resource. In the case of oil for instance, extraction may require such a large initial sunk investment cost that no user will succeed in building a well next to a present user. The form of the conflict, if present, will rather take the form of expropriation, as analysed in section 5. On the other hand, the discovery of oil fields in Oklahoma in the 1920s generated large rents for the initial users and did lead to intense efforts to build wells by additional firms. It that case, it turns out that the law of the country was protecting those incoming users. Conflict occurred in some cases where bargaining on restrictions failed between users, failures that are partly attributed to the large number and heterogeneity of users.[6]

[6]See chapter 56 by Boyce on unitization of oil fields.

Another factor that is largely suspected of affecting internal conflict and resource use is a country's openness to trade. In order to better apprehend the implications of trade, the next section offers a general equilibrium approach to conflict.

7 Trade and resources: A general equilibrium model of conflict

Consider an economy with just two types of goods: natural resources and manufactures, respectively goods 1 and 2. The representative consumer's welfare is represented by $u(x_1, x_2) = x_1^{\alpha} x_2^{1-\alpha}$, where x_1 and x_2 are the quantities consumed. Good 2 is the *numeraire* good, p is the price of the resource good, y_1 and y_2 are the quantities produced, and the *nominal* national product is $Y = py_1 + y_2$. The demands for resource and manufactured goods are thus $x_1 = \alpha Y/p$ and $x_2 = (1-\alpha)Y$.

Labor is the only domestically mobile factor of production; its total size is fixed at $\bar{L}$. We assume a linear production technology in the manufacturing sector, i.e. $y_2 = a_2 L_2$. The production of the resource good, on the other hand, exhibits decreasing returns, with $y_1 = f(L_1)$, $f' > 0$ and $f'' < 0$. In an equilibrium where both sectors are producing, the *nominal* wage rate w will be equal to the marginal product in the manufacturing sector, i.e. $w = a_2$.

In autarky, the price of the resource good is determined by the market clearing conditions between the quantities produced and consumed. In the case of trade, a small open economy assumption implies that the world price is fixed at p_T. Imports and exports are set by a zero trade balance condition. Hence the following:

autarky resource good clearance	$x_1 = y_1$	(21)
autarky manufacturing good clearance	$x_2 = y_2$	(22)
trade price	$p = p_T$	(23)
trade balance	$p(y_1 - x_1) + (y_2 - x_2) = 0$	(24)

Access to the resource input can be either free or restricted. Now in line with the analysis of section 6, restricted access implies that confrontations between resource users and poachers may occur. In our general equilibrium framework, this is represented by the fact that restricted access requires the hiring of guards. We assume that L_1^e denotes the number of guards required for a restricted access regime and that this number is fixed. Once those guards are hired, poachers are completely deterred and the resource can be exploited efficiently. This leads to the following two additional conditions that must be respected in a restricted-access regime:

$$\text{restricted access labor constraint} \quad L_1 + L_1^e + L_2 = \bar{L} \tag{25}$$

$$\text{restricted access resource labor} \quad w = pf'(L_1) \tag{26}$$

In a free-access regime, the presence of a large number of users implies that rents are completely dissipated, i.e. the average product is equal to the wage rate. However, free access does not lead to any confrontation and consequently, no guards need to be hired. The free-access regime thus corresponds to the following two conditions:

$$\text{open access labor constraint} \quad L_1 + L_2 = \bar{L} \tag{27}$$

$$\text{open access resource labor} \quad w = p\frac{f(L_1)}{L_1} \tag{28}$$

The cost of enforcing a restricted access against poachers must be borne by the users themselves. This means that restricted access will only occur in equilibrium when the rents that it generates are sufficient to cover the costs of hiring guards. Let R_1 denote total rents in the resource sector *gross* of guarding costs, i.e. $R_1 = pf(L_1) - wL_1$, and assume that guards are paid the same wage rate as the rest of the labor force. Access will be restricted in equilibrium if the following condition holds:

$$R_1 > wL_1^e. \tag{29}$$

Figure 6 depicts the conflict economy. The origin for the resource sector is located at 0_1. The length of the horizontal axis determines the size of the *directly productive workforce*, i.e. those who are hired to produce resource or manufactured goods. Hence, its has a length of $\bar{L} = \overline{0_1 0_2}$ under free access, but shrinks to length $\bar{L} - L_1^e = \overline{0_1 0_2^e}$ under restricted access. The origins of the manufacturing sector are thus 0_2 or 0_2^e, depending on the access regime that prevails in the resource sector. This accounts for the fact that under restricted access in the resource sector, the generation of rents causes conflict which draws productive resources away from directly productive activities.

The marginal product curve in the manufacturing sector is represented by line $a_2 a_2$. Dotted curve $p_T f'(L_1)$ denotes the value of the marginal product of labor in the resource sector under trade and $p_T f(L_1)/L_1$ is the corresponding average product value curve. The restricted access equilibrium with trade is thus given by point A, with a labor allocation located at L_T^{RA}. The directly

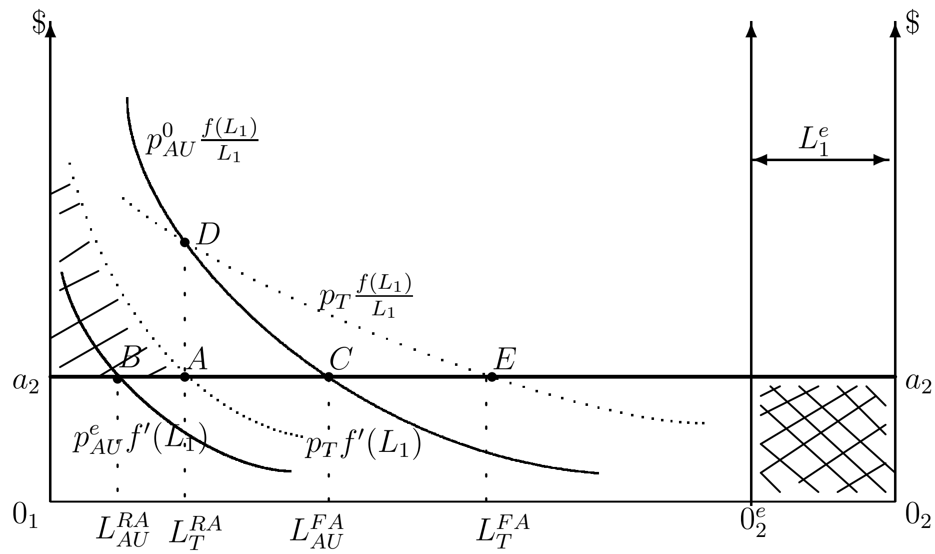

Figure 6: Trade, resources and conflict in general equilibrium

productive labor in the resource and manufacturing sectors is thus given by segments $\overline{0_1 L_T^{RA}}$ and $\overline{L_T^{RA} 0_2^e}$ respectively. Analogously, the free access equilibrium under trade is given by point E, with corresponding labor allocations $\overline{0_1 L_T^{FA}}$ and $\overline{L_T^{FA} 0_2}$. Which of the two equilibria holds hinges on the difference between the gross rents (depicted by the hatched region) and the exclusion costs wL_1^e (depicted by the cross-hatched region).

Under trade, a fixed world price implies that production decisions are disjoint from the demand. But in the case of autarky, for any given resource output level, the resource price increases as more manufactures are produced. This implies that given L_1, when the origin for manufactures is 0_2, the autarkic resource price, denoted p_{AU}^0, is higher than when the origin for manufactures is 0_2^e, denoted p_{AU}^e. For expository purposes, we shall assume that the country has no *classical* comparative advantage in the production of either goods. What this means here is that in a (utopian) economy without conflict, i.e. $L_1^e = 0$, the trade and autarky equilibria coincide at point A, where $p_{AU}^0 = p_T$. This also implies that $p_{AU}^0 < p_T$ for $L_1 > L_T^{RA}$, and conversely. And finally, at labor allocation L_T^{RA}, we have $p_{AU}^e < p_T$. Those general equilibrium price effects have important implications for understanding conflict.

Suppose a setting in which restricted access has the potential to fuel intense conflict in the resource sector, for any of the various reasons discussed in section 6.3. As a result of this, L_1^e takes on such a large value that $R_1 < wL_1^e$ under both autarky and trade, leading to free access equilibria at points C and E. In both cases, the resource is being over-exploited. Trade, however, exacerbates the situation. Indeed, at point C, it can be seen that the world price exceeds the autarky price. This implies that the country exports the resource good under trade. But recall that we began by assuming that the country did not have a comparative advantage in any good. As a consequence of this, the combination of free access and a higher trade price leads to an export of resource goods that should not be exported. Indeed, given that the average product of all workers is equal to a_2 under both trade and autarky, the nominal national income remains equal to $a_2\bar{L}$; the higher trade price, however, shrinks the size of the consumption set. Once again, this underscores the fact that even though there is no conflict in equilibrium, the mere possibility, or threat, of conflict leads to an immiserizing effect of trade when combined with a higher resource price.

Suppose instead that L_1^e is somewhat lower. Given that $p_{AU}^e < p_T$ and $L_T^{RA} > L_{AU}^{RA}$, the gross rents from a restricted access are larger under trade than autarky. Since the cost of restricted access is constant at $a_2L_1^e$, there will thus be situations where trade involves a shift from free access under autarky to restricted access, i.e. from point C to point A. This means that trade, through its higher resource price, induces a better management of the resource.[7] But it also leads to a higher risk of conflict as poachers must now be excluded. Consequently, trade may or may not be immiserizing. It remains immiserizing if the increase in the nominal national income given by the difference between the gross rents and the conflict costs is not large enough to compensate for the higher world price that consumers now face.

8 Glossary

Appropriability: The degree to which establishing control over a good or asset requires appropriative activities. This property is linked to the physical characteristics of the natural resource itself and independent of external factors.

[7]See chapter 20 by Gulati and Kellenberg for additional perspectives on the political-economy of trade and the environment.

Appropriation: In the context of conflict economics, appropriation is presented as a third means of acquiring a good, besides production and exchange. It is present when acquisition requires some amount of appropriative activities.

Appropriative activity: The use of production factors in order to produce force or threat of the use of force.

Conflict intensity: The total amount of appropriative activities being deployed.

Shadow of conflict: Refers to decisions that are influenced by the possibility of conflict even though conflict may not occur.

Contest success function: A function which transforms the appropriative activities of various contenders into either a probability of wining a conflict or the share of a prize to be won.

Nonreplicability: Refers to the case of a factor of production that is necessary for the production of a good but cannot be bought and sold on the market by other potential producers.

9 Suggested readings

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