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Evolutionary determinants of war

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Abstract

This paper considers evolutionarily stable decisions about whether to initiate violent conflict rather than accepting a peaceful sharing outcome. Focusing on small sets of players such as countries in a geographically confined area, we use Schaffer's (1988) concept of evolutionary stability. We find that players' evolutionarily stable preferences widen the range of peaceful resource allocations that are rejected in favor of violent conflict, compared to the Nash equilibrium outcomes. Relative advantages in fighting strength are reflected in the equilibrium set of peaceful resource allocations.

Keywords: Conflict; Contest; Endogenous fighting; Balance of power; Evolutionary stability

JEL Codes: D72; D74

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1 Introduction

Conflict may lead to resource wasteful fighting even in situations in which conflict could be avoided and a peaceful sharing agreement could be reached. The failure to avoid wasteful conflict is a puzzle that attracted much attention and led to a number of rational choice explanations for wasteful fighting, for instance, in international politics. Work in this field has used concepts of game theory to address the role of incomplete information about the rival's strength or fighting ability or the rival's valuation of what can be allocated or shared between the contestants¹, indivisibilities of what can be re-allocated between rivals², the relationship of domestic politics and international conflict³, the lack of peaceful coalition outcomes⁴, the inability to solve conflict by a cooperative bargaining outcome due to time consistency issues and the lack of complete contracts⁵, and the role of multiple equilibria and equilibrium selection^{6,7}. Moreover, there has been a discussion about the relationship between the distribution of power and the likelihood of conflict. For instance, Organski (1968; p.294) argues that a balance of power makes war more likely because "nations are reluctant to fight unless they believe they have a good chance of winning, but this is true for both sides only when the two are fairly evenly matched, or at least when they believe they are". Claude (1962; pp.51-66) views a balance of power as a state of equilibrium and concludes that it has "the compensatory advantage of not assigning any group of states to a position of decided inferiority in the quest for security". Wittman (1979) argues that there is no effect of the power distribution on the likelihood of war because inequality in military power may be counterbalanced by unequal sharing in

¹See, for instance, Brito and Intriligator (1985), Powell (1987, 1988), Morrow (1989), Fearon (1995) and Bueno De Mesquita, Morrow and Zorick (1997) for results and discussion, and more recently Slantchev (2010) on the problem of countervailing signaling incentives and Slantchev and Tarar (2011) on a rationalist theory of mutual optimism.

²See Hassner (2003) and Hensel and McLaughlin Mitchell (2005), and Powell (2006) for a discussion.

³See Hess and Orphanides (1995) and Jackson and Morelli (2007) for two different approaches to this issue.

⁴See, e.g., Jordan (2006) for an analysis of possible coalition outcomes as a function of the distribution of power in pillage games.

⁵See, e.g., Fearon (1996), Garfinkel and Skaperdas (2000), and Powell (2006) and McBride and Skaperdas (2009) for empirical evidence in a conflict experiment.

⁶Slantchev (2003) and Konrad and Leininger (2011).

⁷Jackson and Morelli (2011) provide an overview and discuss further issues including first-strike advantages, the role of political regime, and behavioral aspects such as ideology or revenge.

a peaceful bargaining outcome.⁸

This paper explores a potential reason for why fighting may occur more frequently than what would be expected from this set of explanations. We focus on the generic problem of bargaining about a peaceful settlement in the shadow of war. We abstract from many aspects that have been highlighted in the theories mentioned above and analyze a simple bargaining context in which players face a given peaceful negotiation outcome as a take-it-or-leave-it alternative. Players may either accept this outcome or they may fight with each other. The important novel aspect which we take into consideration, however, is a different rule by which players decide about whether or not to accept a peaceful settlement in the shadow of war: we consider a decision rule that is shaped by an evolutionary process. Forces of mutation and selection lead to evolutionarily stable decision rules. Our main question is whether evolutionarily stable decision making yields more or less fighting than in a Nash equilibrium, and whether it makes peaceful settlement more or less likely.⁹ We remove dynamic aspects of negotiations¹⁰ as well as issues of incomplete information, commitment problems and many of the other aspects that have been addressed and identified as possible reasons for resource wasteful fighting. This is for simplicity only. Our analysis is not meant to replace any of the explanations that have been offered so far, and evolutionarily stable strategies may be seen as supplementary to these theories rather than replacing them.

In a simple bargaining framework decision makers who maximize their own material payoffs compare their own material payoff from acceptance of the peaceful settlement with their own expected material payoff from fighting.¹¹ In order to set-

⁸See also Garnham (1976), Bueno de Mesquita (1981) and Siverson and Sullivan (1983) for further discussions and empirical assessments as well as Wagner (1994) for considerations of military conflict accompanying and influencing the process of bargaining.

⁹Before evolutionary explanations for decision rules about peaceful settlement or military conflict between nation states are applied, it is important to discuss whether or to what extent decisions by countries or by country leaders or governments are shaped by evolutionary forces. There is a small literature that argues that such evolutionary forces may play a role. Wagener (2013), for instance, suggests that procedures such as yardstick competition or imitation behavior on successful policy making may shape political institutions and internal decision procedures, some of which are also relevant for negotiations and decisions in international politics.

¹⁰Dynamics are important for understanding and explaining the duration of war and the relationship between duration, the cost of war, considerations of discounting. See, for instance, Wittman (1979), Werner (1998) and Wagner (2009) and Maoz and Siverson (2008) for a survey.

¹¹Depending on how they reached this decision stage, the decision about peaceful sharing may be the decision about ending an ongoing war. It may also be the decision which players make in a

tle peacefully, if one of the contestants has a higher expected payoff in the fighting regime than the other due to, for instance, a higher military strength or a lower cost of fighting, this contestant requires a higher payoff in case of a peaceful settlement in order to find such a settlement attractive; the converse applies for the other contestant. In fact, this is the underlying logic of bargaining models of war. As Wittman (1979, p.751) puts it: "War and peace are substitute methods of achieving an end. If one side is more likely to win at war, its peaceful demands increase; but at the same time the other side's peaceful demands decrease." Hence, peaceful resource allocations that are acceptable for both of the conflicting parties take potential asymmetries of the players in their fighting abilities or their fighting costs into account, or, more generally speaking, asymmetries in their net payoffs in case of war. Suppose there are two rivals A and B who compete for a stock of resources of given size R that is equally valuable to them. If both rivals are of equal strength (have the same costs and success probabilities in case of a war), they may agree on a symmetric bargaining outcome: Both may accept if they receive one half of the resources, and they may prefer this outcome to military conflict which is resource wasteful and, therefore, gives both of them less than half of the resources in expectation. Given this logic, A and B may even accept unequal sharing rules, provided that the recipient prefers even this smaller share to the prospect of a costly war. This typically gives a whole range of sharing rules that are acceptable to both players. A similar logic applies if players are of unequal strength. If rival A is much stronger than rival B , then A has a higher expected payoff from war than B . As long as this asymmetry is not too strong, A and B should be willing to accept a symmetric peaceful sharing rule, given the cost of war. The set of acceptable sharing rules shifts if players A and B become more unequal regarding their military strength, but the basic logic of comparing own material payoffs in the peaceful outcome and in the fighting outcome remains the same.

We depart from this concept and apply the concept of evolutionary stability for small groups introduced by Schaffer (1988).¹² The theoretical analysis of evolutionary

status of peace when they decide whether or not to avoid a war that is looming in case of negotiation failure.

¹²For other applications in the context of contests see Leininger (2003) and Hehenkamp, Leininger and Possajennikov (2004). For applications to the indirect evolutionary approach as introduced by Güth and Yaari (1992) on this problem see Eaton and Eswaran (2003) and Leininger (2009), for implementation of the evolutionarily stable efforts by deflated cost perceptions or low subjective effort cost see Wärneryd (2012) and for inflated prize perceptions see Boudreau and Shunda (2012).

stability has originally been shaped by the concepts introduced by Maynard Smith and Price (1973) and Maynard Smith (1974) in evolutionary biology. This stability concept has been derived for infinitely large populations, where there is a very close correspondence between the Nash equilibrium for players who maximize the absolute amount of their own material payoff and the evolutionarily stable strategies in such populations. However, when addressing the context of a small set of players such as countries or sovereign states, this framework is not appropriate. Indeed, the total number of sovereign players is finite. Moreover, conflict has often been restricted to a small area with a very limited number of players¹³, and an evolutionary analysis in this context must take this small number issue into account.

Our results show that evolutionary forces with small numbers of players lead to a different decision making. Evolutionary forces narrow down the range of possible peaceful sharing rules which players accept. Players are willing to sacrifice some of their own material payoff if this improves their material payoff relative to the material payoff of others. In other words, players are willing to choose war which is resource wasteful and leads to a lower own material payoff if this choice harms their rivals even more, compared to the choice of peaceful settlement. As we assume that war is resource wasteful, Pareto efficiency in our framework implies a peaceful settlement. Moreover there is a non-empty set of peaceful settlements that are both Pareto efficient and Pareto improvements for both players, compared to fighting. This set is usually referred to as the core in bargaining problems. The core is non-empty in our framework, regardless of how asymmetric players are with respect to their military strengths. However, not all elements in the core are possibly chosen by evolutionarily stable strategies. The set of peaceful settlements that are acceptable to both rivals as evolutionarily stable strategies is a proper subset of the core, and this subset is smaller the smaller the number of players.

The key for understanding these results is as follows: The concept of evolutionary stability in small groups brings about concerns for relative rather than absolute material success. Players who apply a given strategy do well in the evolutionary process if this strategy makes them more successful than players who apply other strategies. And there are two reasons for why a given strategy makes a player better-off relative

For spite and altruism in the implementation of evolutionarily stable efforts see Eaton, Eswaran and Oxoby (2011) and Konrad and Morath (2012).

¹³The competition between Italian city states as in the Great Italian Wars in the 15th and 16th century may serve as an example of such a geographically restricted conflict area.

to players using other strategies: First, the strategy may increase the player's own absolute payoff. Second, the strategy may harm other players and reduce their absolute payoff. If fighting allocates more evenly what remains after a war, acceptance of a peaceful settlement that awards a larger share of the peace dividend to the other player may then be less attractive than to sacrifice the peace dividend and fight.¹⁴

In Section 2 we describe the framework and define evolutionary stability in this framework borrowing from Schaffer's (1988) definition. In Section 3 we derive our main results. We determine an equilibrium in evolutionarily stable strategies, compare this equilibrium to the Nash equilibrium and derive the comparative static properties of this comparison. Section 4 concludes.

2 The framework

We study an evolutionary context with $n = 2m$ players in the population with $m \geq 1$ being an integer. For illustration, we may think of these as the leaders or the governments of sovereign states. These players interact in a bargaining game that constitutes the state game and that is governed by the following rules. At the beginning each player is teamed up with one other player in a specific conflict. The assignment of players is purely random. We will study a representative pair and denote this group by A and its members by i and $-i$. The group has to allocate a given prize of size 1 between i and $-i$. As part of the specific conflict, players have an option to divide the prize peacefully; this option allocates a share a_i to player i and a share $a_{-i} = 1 - a_i$ to player $-i$. Each pair of players may face a different a_i , as this share is drawn independently from the same probability distribution in all groups, and the distribution from which a_i is drawn has full support $[0, 1]$. For instance, every prize may come in two pieces of size a_i and a_{-i} which cannot be further subdivided.

Players may accept or reject this peaceful allocation. As will be described in more detail below, depending on the players' decisions whether or not to accept this division of the prize, the players in a group may share peacefully and obtain a material payoff of a_i and a_{-i} , respectively, or they may enter into a phase in which they fight about the full prize. If the players within a group fight, then each player chooses an effort

¹⁴Note that the argument here is quite different from an argument suggesting that more belligerent players are more successful because they expand and spread their attitudes. Frequent fighting is not evolutionarily advantageous per se.

($y_i \geq 0$ and $y_{-i} \geq 0$), measured in material units of the prize. The action $y_i \in [0, \infty)$ is the amount of material resources that player i expends in the contest if a fight takes place in his group. The fight is described by a Tullock (1980) lottery contest.¹⁵ Player i earns the prize with a probability that depends on the player's share in total fighting effort and the two players' 'fighting strengths' b_i and $b_{-i} = 1 - b_i$. More precisely, if fighting takes place, i 's winning probability¹⁶ is equal to

$$p_i = \frac{b_i y_i}{b_i y_i + b_{-i} y_{-i}}.$$

Altogether, player i 's material payoff is $\pi_i = a_i$ if the players in group A share peacefully and it is equal to

$$\pi_i = \frac{b_i y_i}{b_i y_i + b_{-i} y_{-i}} - y_i \tag{1}$$

if the players in group A fight. The fighting strengths b_i and $b_{-i} = 1 - b_i$ are assigned to the players in a group at the same time as the rule (a_i, a_{-i}) that governs possible peaceful sharing. We assume that, in each group, b_i is an independent random draw from a probability distribution with support on the open interval $(0, 1)$. The values (a_i, b_i) are observable. This sets the framework in which players solve the distributional conflict between them.¹⁷

An evolutionary strategy for a player i is denoted by $\sigma = (\phi(a_i, b_i), y(a_i, b_i))$ and is defined at the stage before the players are assigned their group and learn about the specific (a_i, b_i) that applies in their own group or in other groups. It consists of a pair of 'actions', that is, descriptions about the player's behavior as a function of the parameters a_i and b_i that constitute the player's environment. Apart from the effort $y(a_i, b_i)$ conditional on fighting, the function $\phi(a_i, b_i)$ determines a player's choice whether to fight and is a threshold function; a threshold value α defines the smallest peaceful share that i is willing to accept. Hence, i fights for all a_i which are smaller than this threshold and accepts all a_i which are (weakly) larger than this threshold

¹⁵This contest success function has been axiomatized by Skaperdas (1996) and has been widely used. See Konrad (2009) for an overview of applications and microeconomic underpinnings.

¹⁶Assuming that players are risk neutral, this probability of obtaining the prize can also be interpreted as the share in the resources (of size one) a player appropriates in the fight.

¹⁷The restrictions of $a_i + a_{-i} = 1$ and $b_i + b_{-i} = 1$ are only used to simplify notation; all results go through with minor notational changes as long as $b_i > 0$ and $b_{-i} > 0$ and as long as i can observe (a_i, b_i) and (a_{-i}, b_{-i}) in his group at the beginning of the state game.

α . As it will turn out, the equilibrium threshold value for a choice of fight will be a function of the own fighting ability b_i and the fighting ability $b_{-i} = 1 - b_i$ of the player $-i$ who is in the same group as i ; hence, $\alpha = \alpha(b_i)$, and the function ϕ indicates a choice to fight if and only if $a_i < \alpha(b_i)$.

The evolutionary strategy $\phi(a_i, b_i)$ describes a player's threshold $\alpha = \alpha(b_i)$ as regards his fighting intentions. In addition, we need to make an assumption about how players' fighting intentions translate into whether the players in a group settle peacefully or whether they fight: For a given (a_i, b_i) , the comparison of a_i and a_{-i} with the thresholds $\alpha(b_i)$ and $\alpha(b_{-i})$ provides a mapping into a probability $q_l = q(l)$ where $l \in \{0, 1, 2\}$ is the number of members of this group who choose to fight (that is, the number of players with $a_i < \alpha(b_i)$). Given l , the peaceful allocation is implemented with probability $1 - q_l$, and a fight takes place with the remaining probability q_l . We can assume for this function $q(l)$ that, for a given (a_i, b_i) , the following inequalities hold: $0 \leq q_0 < q_1 < q_2 \leq 1$. Fighting is more likely the more individuals in a group have a threshold that is higher than the share a_i and, therefore, reject the peaceful allocation.

For a definition of an evolutionarily stable strategy (an "ESS") and a one-step mutation, suppose that $n - 1$ players follow a given strategy $\sigma = (\alpha^E, y^E)$ that determines a player's actions as a function of the distribution (a_i, b_i) in his group.¹⁸ A one-step mutation from this strategy is a pair $\sigma^M = (\hat{\alpha}, \hat{y})$ that deviates from σ in exactly one component, either in the threshold function α_i or in the function y . If all but one individual choose σ and the remaining individual chooses σ^M , we denote this strategy profile as (σ^M, σ_{-M}) . Moreover, we denote by $\Pi^M(\sigma^M, \sigma_{-M})$ the expected payoff of the player who has the mutant strategy and by $\Pi(\sigma^M, \sigma_{-M})$ the expected payoff of the other players who follow σ . The "expected" in these expected payoffs refers to the state at the beginning of the state game, hence, before players learn which group they are assigned to and before they learn the values of (a_i, b_i) . Thus, $\Pi^M(\sigma^M, \sigma_{-M})$ takes into account that the mutant is in a group which consists of the mutant and one other player who follows σ . And $\Pi(\sigma^M, \sigma_{-M})$ takes into consideration that a non-mutant is in a group with the mutant with probability $1/(n - 1)$ and in a group without a mutant with the remaining probability $(n - 2)/(n - 1)$, and that he is assigned any of the types with equal probability. Building on Schaffer (1988), we

¹⁸As we will see in the next section, a player's equilibrium fighting effort conditional on fighting only depends on b_i and b_{-i} but not on a_i .

define:

Definition 1 *The strategy σ is an evolutionarily stable strategy if there is no one-step mutation σ^M from σ such that $\Pi^M(\sigma^M, \sigma_{-M}) - \Pi(\sigma^M, \sigma_{-M}) > 0$.*

This definition highlights the role of relative, rather than absolute material payoff. Behind this definition, though it is not spelled out explicitly, is a theory of population dynamics for which we can only provide an intuition here. Suppose there is an infinite sequence of state games, just as the one described above, with the same population size in each state game. Suppose further that the composition of ‘types’ (defined by the evolutionary strategy they apply) in the population of stage t is a function of the composition of ‘types’ in the previous stage game and of the performance of these types in this previous stage. If players of type σ^M , that is, players who are conditioned to apply the mutant strategy σ^M , have a higher expected material reward than players who apply the actions determined by strategy σ , where all others also apply strategy σ , then the players applying σ^M do systematically better than other players. If being better-off than others in terms of material payoff translates in a higher survival or reproduction rate, then the population of players using σ^M is likely to grow from state game $t - 1$ to state game t , and the population of players who apply σ is likely to shrink. This is what it means for strategy σ to be not evolutionarily stable; it is vulnerable due to the existence of strategy σ^M . Only if there is no strategy σ^M that makes σ vulnerable in this sense, then a population of players applying σ cannot be invaded by a mutant. As discussed in the introduction and in more detail by Wagener (2013), applied to sovereign states, the growth or decline of certain decision rules need not be seen as the result of extinction or reproductive success in a biological sense. We may, for instance, consider strategies such as σ as the outcome of a process in which governments or country leaders imitate the behavior of governments or leaders of other countries who generated a higher material payoff. A government with some given decision rules spreads if this type of government has imitators; that is, if other governments give up their old decision rules and adopt the decision rules of this government.

3 Stable peaceful allocations

Using Definition 1, we can now characterize an equilibrium in evolutionarily stable strategies. This leads to our main result:

Proposition 1 *For finite $m \geq 1$, there is an equilibrium in evolutionarily stable strategies where*

$$\alpha^E(b_i) = b_i \frac{1 + (n-2)b_i}{n-1} \quad (2)$$

such that player i accepts the peaceful division if and only if $a_i \geq \alpha^E(b_i)$ and

$$y^E(b_i) = \frac{n}{n-1} b_i (1 - b_i).$$

Proof. First we show that the evolutionarily stable fighting effort y^E is the same for both players i and $-i$ and equal to

$$y^E = \frac{n}{n-1} b_i (1 - b_i). \quad (3)$$

Suppose that $y_{-i} = y^E$ as in (3). One-step deviations in y_i only affect the *material* payoff of the player who is in the group with the mutant player and only if this group fights. Hence, one-step deviations in y_i do not increase a player's fitness if y^E maximizes

$$\left(\frac{b_i y_i}{b_i y_i + (1 - b_i) y^E} - y_i \right) - \frac{1}{n-1} \left(\frac{(1 - b_i) y^E}{b_i y_i + (1 - b_i) y^E} - y^E \right) - \frac{n-2}{n-1} \Pi(\boldsymbol{\sigma}). \quad (4)$$

The first term in brackets is i 's material payoff of i as a function of y_i and the second term in brackets is the material payoff of the player $-i$ who is in the same group as i , both conditional on fighting. The term $\Pi(\boldsymbol{\sigma})$ is the (expected) material payoff of all other players who are not in the same group with i but all follow the candidate evolutionarily stable strategy. Maximization of (4) with respect to y_i yields the first order condition

$$\frac{n}{n-1} \frac{b_i (1 - b_i) y^E}{(b_i y_i + (1 - b_i) y^E)^2} = 1$$

which is solved for $y_i = y^E$ and yields (3).¹⁹ Hence, one-step deviations from the effort y^E do not increase a player's fitness.

Using (3), we can compute a player's material payoff in the equilibrium with evolutionarily stable strategies conditional on fighting. Since in a monomorphic equilibrium in evolutionarily stable strategies, $y_i = y_{-i} = y^E$, player i wins the prize with probability

$$p_i = b_i$$

in case of fighting and hence gets an expected material payoff of $p_i - y^E$ in case of a fight which is equal to

$$\frac{(n-1)b_i - nb_i(1-b_i)}{n-1} = \frac{nb_i^2 - b_i}{n-1}. \quad (5)$$

Now turn to the choice of the threshold for fighting. In the candidate evolutionarily stable strategy, player i chooses the peaceful settlement if and only if

$$a_i \geq \alpha^E = b_i \frac{1 + (n-2)b_i}{n-1}.$$

We need to show that this candidate choice fulfills Schaffer's criterion. Suppose that all other players follow strategy σ . Consider the fitness of player i depending on this player's threshold function $\hat{\alpha}$. We ask which $\hat{\alpha}$ maximizes i 's fitness. Suppose that, if i chooses to fight, the probability that a fight takes place inside i 's group increases from q_l to q_{l+1} . For any given (a_i, b_i) , if player i chooses to fight rather than the peaceful settlement, this changes i 's fitness for this assignment of shares by

$$\begin{aligned} & (q_{l+1} - q_l) \left[\frac{nb_i^2 - b_i}{n-1} - \frac{1}{n-1} \frac{n(1-b_i)^2 - (1-b_i)}{n-1} - \frac{n-2}{n-1} \Pi(\sigma) \right] \\ & + ((1 - q_{l+1}) - (1 - q_l)) \left[a_i - \frac{1}{n-1} (1 - a_i) - \frac{n-2}{n-1} \Pi(\sigma) \right]. \end{aligned} \quad (6)$$

The term in square brackets in the first line is i 's relative expected material payoff if fight takes place in i 's group: The expected material payoffs of the two players who fight are as in (5), and all $(n-2)$ players who are not in the same group as i get an expected material payoff of $\Pi(\sigma)$. The term in square brackets in the second line is

¹⁹Since the objective function is strictly concave, the first order condition is sufficient in determining the optimal choice of y_i .

i 's relative material payoff in case no fighting takes place in i 's group: Player i gets a share a_i and the other player in his group gets $a_{-i} = 1 - a_i$; all other $(n - 2)$ players again get an expected material payoff of $\Pi(\boldsymbol{\sigma})$.

With (6), player i 's fitness does not increase in case i chooses to fight if and only if

$$(q_{l+1} - q_l) \left(\frac{(n-1)b_i^2 - b_i(1-b_i)}{(n-1)} - \frac{1}{n-1} \frac{(n-1)(1-b_i)^2 - b_i(1-b_i)}{(n-1)} \right) - (q_{l+1} - q_l) \left(a_i - \frac{1}{n-1} (1-a_i) \right) \leq 0.$$

Solving this inequality for a_i yields a critical level of a_i such that i 's fitness is higher in case i fights if and only if a_i falls short of this critical level. This critical level defines the optimal threshold as

$$\alpha^E(b_i) = b_i \frac{1 + (n-2)b_i}{n-1}.$$

Note that, unlike the evolutionarily stable effort, $\alpha^E(b_i) = \alpha^E(b_{-i})$ if and only if $b_i = b_{-i}$. The choice of cut-off rule α^E maximizes a player's fitness ex-ante, i.e., prior to the matching in pairs and to the assignment of sharing offers a_i and fighting powers b_i . ■

In the equilibrium in evolutionarily stable strategies, a player chooses to fight whenever his peaceful resource share is too small (smaller than $\alpha^E(b_i)$), for which fighting increases i 's *relative* material payoff (i.e., his fitness). Thus, relevant for the decision whether to fight is the own and the other players' expected material payoff in case a fight takes place. Since a player's material payoff conditional on fighting depends on his relative fighting strength, the same holds for the cut-off value α^E .

Corollary 1

(i) $\alpha^E(b_i) > \alpha^E(b_{-i})$ if and only if $b_i > b_{-i}$, that is, the stronger player requests a higher share.

(ii) If $n = 2$, then $\alpha^E(b_i) = b_i$, that is, the requested share is equal to the player's equilibrium winning probability $p_i = b_i$ conditional on fighting.

The stronger a player is relative to the other player in his group, the larger will be the share of resources that this player demands and that guarantees that a peaceful agreement can be reached (Corollary 1(i)). If the players within a group are

sufficiently asymmetric in terms of their fighting strength, the peaceful contracts (a_i, a_{-i}) that are accepted in the equilibrium require an asymmetric distribution of the resources. Moreover, if n is small, the threshold for acceptance of the peaceful arrangement gets closer to the individual's winning probability in case a fight takes place. This holds despite of the fact that, in the contest, the players would also have to bear the cost of effort. In the case where $n = 2$, the threshold for acceptance of the peaceful arrangement is exactly equal to the individual's winning probability in the contest (Corollary 1(ii)). In other words, in the only peaceful contract that is evolutionarily stable, the individuals' resource shares are equal to their prospective winning probabilities in case of a fight: $(\alpha^E(b_i), \alpha^E(b_{-i})) = (b_i, b_{-i})$. Hence, if $n = 2$, the only peaceful contract that is sustainable in the evolutionarily stable equilibrium allocates resource shares to the players that exactly reflect the balance of power.

In what follows, we compare the evolutionarily stable strategy (α^E, y^E) with the choices that emerge if all players maximize their absolute material payoff. For this purpose, consider the subgame perfect Nash equilibrium of a two-stage game: Once players are allocated to their groups and learned the (a_i, b_i) that applies in their group, players simultaneously choose whether to accept or reject the possible peaceful sharing arrangement. This choice constitutes stage 1 in a two-stage game. Let $l \in \{0, 1, 2\}$ be the number of players in a group who have chosen to fight. As a consequence of these choices, the players in a group share peacefully with a probability of $1 - q(l)$, in which case the game ends and the players obtain the resource shares a_i and $a_{-i} = 1 - a_i$. A fight takes place with the complementary probability $q(l)$; in this case the players in this group simultaneously choose their fighting efforts y_i and y_{-i} (measured in material units of the prize) in stage 2 of the game. As before, player i 's winning probability in the contest is equal to $(b_i y_i) / (b_i y_i + b_{-i} y_{-i})$.

Proposition 2 *For given (a_i, b_i) , in the subgame perfect Nash equilibrium, player i accepts the peaceful division if and only if $a_i \geq \alpha^N(b_i)$ where*

$$\alpha^N(b_i) = b_i^2. \tag{7}$$

Proof. First consider i 's expected payoff conditional on fighting. Solving the game by backward induction, in stage 2, players maximize their expected material payoff

which is equal to

$$\frac{b_i y_i}{b_i y_i + b_{-i} y_{-i}} - y_i.$$

As is known from the literature on contests, this yields equilibrium effort choices that are equal to $y_i = y_{-i} = y^N$ where

$$y^N = b_i(1 - b_i). \quad (8)$$

Since $y_i = y_{-i} = y^N$, player i 's equilibrium winning probability is equal to

$$p_i^N = b_i, \quad (9)$$

and his expected material payoff from fighting is equal to $p_i^N - y^N$ or, equivalently,

$$\pi_i^N = b_i^2. \quad (10)$$

In stage 1, i strictly prefers to fight if and only his continuation payoff in stage 2 (as in (10)) is strictly larger than what he would get in case of peace. Therefore, player i rejects the peaceful sharing opportunity if and only if $a_i < b_i^2$. ■

The results in Proposition 1 and Proposition 2 allow for a comparison of players' evolutionarily stable behavior and their Nash equilibrium behavior as regards the peaceful sharing option.

Corollary 2 *The threshold $\alpha^N(b_i)$ that player i chooses in the Nash equilibrium is smaller than the threshold $\alpha^E(b_i)$ that constitutes the evolutionarily stable strategy.*

Proof. For a proof we compare the cut-off $\alpha^N(b_i)$ in the Nash equilibrium to the cut-off $\alpha^E(b_i)$ that players choose in the equilibrium in evolutionarily stable strategies. Since

$$b_i \frac{1 + (n-2)b_i}{n-1} > b_i \frac{b_i + (n-2)b_i}{n-1} = b_i^2,$$

we have $\alpha^E(b_i) > \alpha^N(b_i)$. ■

The main result of Corollary 2 is that the cut-off value $\alpha^E(b_i)$ in the evolutionarily stable equilibrium is strictly larger than the cut-off value $\alpha^N(b_i)$ in the subgame perfect Nash equilibrium. If the cut-off value is determined by what is an evolutionarily stable strategy, then the player is more demanding in a given situation than a player who maximizes his absolute material payoff and interacts with players who do the

same in a Nash equilibrium. This holds for all finite populations, i.e., for all finite $m > 0$. In other words, the range $[0, \alpha^E(b_i))$ where player i rejects the peaceful sharing opportunity and prefers to fight in the evolutionarily stable equilibrium is larger than the corresponding range that results from the maximization of own material payoffs. Players' stable evolutionary strategies make them reject peaceful allocations that give them a higher payoff than what they would get if they fight. This holds despite of the fact that the evolutionarily stable fighting effort y is higher than the fighting effort that maximizes the material payoff ($y^E > y^N$), that is, even though there is higher rent dissipation in the evolutionarily stable fighting outcome than in the Nash equilibrium.

To gain some intuition for this result, consider the case where all players have the same fighting strength, $b_i = b_{-i} = 1/2$. In this case, players choose to fight in the Nash equilibrium whenever their peaceful share is smaller than $\alpha^N = 1/4$. The evolutionarily stable strategy, however, is not to accept peaceful shares below $\alpha^E = (1/4)(n/(n-1)) > 1/4$. If a player i decides to fight, this has two effects on i 's fitness. First, since fighting reduces i 's absolute material payoff, it also reduces i 's payoff relative to players who are not in the same group and whose payoffs are not affected by i 's decision to fight. Second, fighting also reduces the payoff of the player $-i$ who is in the same group as i , and hence increases i 's fitness (relative to $-i$). The smaller n , the more important is this second effect. In case of $n = 2$, i will not accept any resource share that is smaller than the resource share of $-i$ (i.e., $\alpha^E = 0.5$) because fighting will restore equality of payoffs of the two players. On the other hand, a larger n causes the direct comparison with $-i$ to be less important for i 's overall fitness. By rejecting the peaceful sharing with $-i$ the player can reduce only the fitness of $-i$, but there are many other players whose fitness i cannot affect. Hence, α^E is decreasing in n .

Figure 1 illustrates the deviation of α^E from α^N for the case of $b_i = b_{-i}$ as a function of n . It shows that there is a range of possible sharing arrangements that are accepted by players in the Nash equilibrium but rejected in the context of evolutionarily stable strategies. This range narrows with an increase in the number of players n . As is well known, for $n \rightarrow \infty$ the evolutionarily stable strategies coincide with the strategies that constitute a Nash equilibrium.

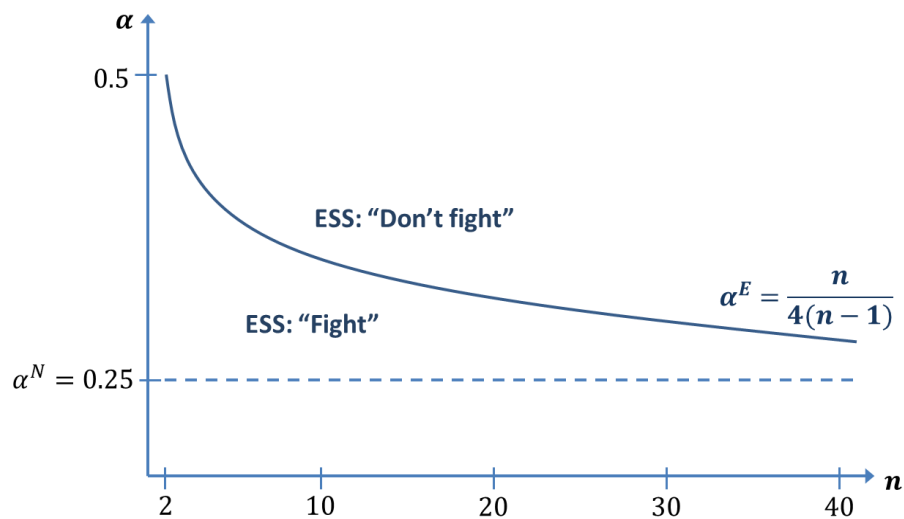


Figure 1: The evolutionarily stable threshold for fighting (example for the case of $b_i = b_{-i}$).

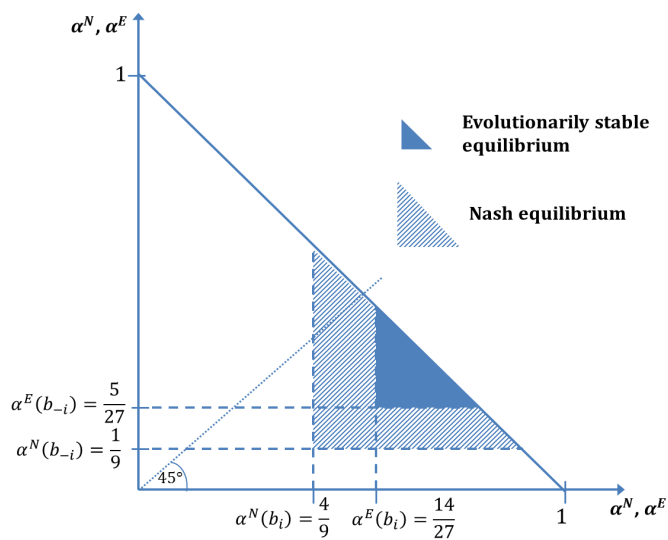


Figure 2: Peaceful resource allocations in the Nash equilibrium and in the equilibrium in evolutionarily stable equilibrium (example for the case of $b_i = 2/3$, $b_{-i} = 1/3$, and $n = 4$).

Figure 2 illustrates the role of asymmetric strength. Here, the thresholds for choices of peace are shown for the Nash equilibrium ($\alpha^N(b_i)$ and $\alpha^N(b_{-i})$) and for the equilibrium in evolutionarily stable strategies ($\alpha^E(b_i)$ and $\alpha^E(b_{-i})$), for the case of $b_i = 2/3$, $b_{-i} = 1/3$, and $n = 4$. The shaded areas correspond to the set of resource allocations that avoid fighting. All peaceful contracts that divide the prize of size one lie on the "budget constraint" $a_{-i} = 1 - a_i$. The set of peacefully sustainable resource allocations is shifted towards the stronger player i . While in the Nash equilibrium a symmetric distribution of the resources avoids fighting in this example, it is evolutionarily stable for the stronger player not to accept such a symmetric distribution but to demand a larger share of the resources.

4 Conclusions

The theory result derived in this paper provides a possible explanation for violence in an environment in which peaceful settlement would be feasible and in situations in which the choice of peaceful settlement would be the individually optimal strategy for players who maximize their own material payoffs. The result has implications for explaining the emergence of violent conflict. If the players' strategies are shaped by evolutionary forces, this predicts that players who choose whether to settle peacefully or to fight frequently choose to fight even if this reduces their own material payoff. Consequently, the range of peaceful resource allocations that is evolutionarily stable is smaller than the corresponding range in the subgame perfect Nash equilibrium.

The balance of power has implications for the feasible resource allocations that can avoid the emergence of conflict. Players reject resource allocations that do not coincide with the relative fighting strengths in a conflict. In other words, the threshold for their resource share below which players reject peaceful allocations is a function of the prospective success probability in a conflict. If, however, bargaining outcomes reflect potential imbalances of power, such imbalances do not make violent conflict more likely.

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