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Studies on Evolutionary Warfare Strategies: from natural to societal conflicts

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INTRODUCTION TO THE TOPIC

In our world, both animals and humans, when they can be considered different species, have always been fighting among members of their own species. And in most of the cases rivals are not willing nor ready to fight until death. As humans have conflicting opinions and most of the contrasts can be solved verbally, at the same manner animals have conflicting desires and needs, but usually duels do not escalate except in the prey-predator scenario. However, if we expect humans to be "reasonable", we can't say the same thing for animals. As documentaries show, in the animal kingdom it is often the case of "*mors tua, vita mea"*[1] (literally "Your death, my life", where the death of the opponent is necessary for the one to survive), thus we would expect animals to behave in a lethal manner more than not. If so, one question would remain unanswered: "Why can we observe limited war in animal fights?". Why do animals in some cases give up on their food or on their reproductive possibility without having dueled until death?

This seemed to be one of the most debated questions by biologists of the twentieth century. By then, the most religious hypothesis upon the theological fixism[2] were being overcome by new discoveries of science brought by brave men as Darwin and "his Bulldog"[3] Huxley (to name a few). First Darwin in 1859 with *"On The Origin of Species"* and then Huxley half a century after in *"Evolution & ethics and other essays"* modelled the theory according to which species are not fixed entities, but rather dynamic populations constantly changing through variation, selection, and adaptation to their environment. The following passage from Huxley's work represents one of the most elegant answers to our question, ruling out for the unlimited struggle for existence in human society:

> *"The first men who substituted the state of mutual peace for that of mutual war, whatever the motive which impelled them to take that step, created society. But, in establishing peace, they obviously put a limit upon the struggle for existence. Between the members of that society, at any rate, it was not to be pursued à outrance. And of all the successive shapes which society has taken, that most nearly approaches perfection in which the war of individual against individual is most strictly limited."*[4]

Despite Huxley was referring to the formation of human society, an analogous concept of *limited war* can be extended to the animal kingdom. As Darwin wrote in *"The Descent of Man"* or *"On the Origin of Species by means of Natural Selection*", natural selection often favors traits which limit the use of excessive violence within the species, since its ultimately long-term survival depends on the health and number of its very own individuals. Darwin and Huxley together have been one of the first pioneers to understand the work of nature: who has as ultimate scope the survival of the species and eliminates all the threats and weaknesses through a dynamic process known as *natural selection* that operates among time and generations.

[1] "Mors tua, vita mea" is a Latin proverb meaning "your death, my life," commonly cited in medieval collections of sayings (Proverbia Communia) and used to express the idea that one's survival often depends on the downfall of another.
[2] biological theory according to which plant and animal species are designed to always remain the same, without undergoing any biological change.
[3] term due to his staunch support of Darwin's theories.
[4] https://origin-rh.web.fordham.edu/halsall/mod/1888thhuxley-struggle.asp

This species-centric view of natural selection was refined by Richard Dawkins, who drew another very original attempt in his work "*The Selfish Gene"* in the second half of the twentieth century. Dawkins, while agreeing with his predecessors on the mechanism of evolution, proposes a substantial shift in perspective: natural selection doesn't ultimately serve the survival of the species, but rather the survival of genes. He defines living organisms as "survival machines" built by genes in order to ensure their own existence throughout time. In his work he emphasizes that animals refrain from being aggressive to increase their reproductive possibilities and keep their genes alive through their prole rather than altruism, or again, as animals are mostly nice to their relatives with respect to strangers as they all share genes. *"Dawkins repeatedly stresses that genes aren't actively choosing to be "selfish," since genes aren't conscious. Rather, genes provide instructions for building embryos, like "build an embryo that will have long legs" (this helps organisms run faster and escape from predators), or "build an embryo that will chirp when there's food nearby" (this benefits a chick's nearby genetic relatives). These behavioral traits are a blind gamble: they're the result of genes randomly shuffling in and out of chromosomes in sex cells. If the resulting behavioral traits happen to keep the organism alive long enough to reproduce, the gene for that trait will be passed on."*[5]

Despite all these attempts, none of the theories above seems enough explanatory alone to the biologists Maynard and Price. Indeed, in their work of 1973 *"The Logic of Animal Conflict"* they stress out how there must be an individual benefit too for animals when adopting limited-war strategies, since animal instinct usually suggests behavior according to the biggest benefit they can obtain in the short-term. In the attempt to find the individual fitness behind the limited-war supremacy, Maynard conducted a complete study on the animal conflicts which will be the main focus of this thesis. His work regarding such topic divides mainly into two models: the aforementioned work co-authored with Price, and a sequent paper in 1974 on *"The Theory of Games and the Evolution of Animal Conflicts"*.

These two complementary models study how animals engage in ritualized contests and their strategies, examining respectively both physical confrontations ("tournaments"), where the strongest or most resilient opponent prevails, and "displays", in which victory is determined by persistence rather than brute force.

By integrating these two seminal works, this thesis aims to examine how game theory models explain the evolution of conflict resolution in animals, highlighting strategic stability, escalation, and

[5] https://www.litcharts.com/lit/the-selfish-gene/summary

retaliation in competitive behaviors. The following sections will explore these theories in depth, providing a modern reinterpretation of the models and a wider application to human sciences.

Especially, the final part of this work will extend the results to human conflict dynamics, drawing parallels between animal contests and strategic interactions in international relations. Indeed, the deterrence theory (respectively, retaliation in animal conflicts) is essential for maintaining stability between major global powers nowadays. At the same time, the animal world offers valuable lessons on how deterrence can minimize violence, encourage cooperation and create unexpected opportunities for coexistence, showing that conflict does not always have to end in destruction.

THE THEORY OF GAMES AND THE EVOLUTION OF ANIMAL CONFLICTS

INTRODUCTION

In the paper John Maynard Smith seeks to address our fundamental question in the attempt to find an individual benefit, rather than a species-level one, that better explains limited-war strategies in the animal behaviour. In this sequent work Maynard studied the interactions during animal displays, defined as ritualized contests in which animals compete on endurance and signalling rather than aggression, with the support of a model based on **Game Theory**, which was only at its earlier stages.

Game Theory is indeed a mathematical framework that models strategic decision-making interactions among individuals whose outcome depends both on their own choices and on those of their opponent. In Game Theory models, or *"games",* each player has primarily the scope of maximizing their own fitness, or *"payoff"*. Using such framework, Maynard formalizes animal interactions as strategic games, where each contestant, or animal, must decide how long to persist according to their expected costs and benefits. Indeed, since engaging in prolonged contests consumes energy and increases the vulnerability to other threats, natural selection favours strategies that optimize the trade-off between endurance and retreat. To model the game the author assigns a payoff to each different strategy, considering factors as energy expenditure, the probability of winning and the consequences of adopting different levels of persistence. Through a mathematical analysis, he demonstrates that there exists an ESS, which ensures that the population maintains a stable behavioural equilibrium where no alternative strategy can successfully replace the existing one.

The importance of his work lies in its ability to explain why ritualized displays persist in nature, despite the presumed advantage of aggression in competitive scenarios. Indeed, displays offer a way for individuals to resolve conflicts while minimizing the risk of serious injury, which could reduce their chances of future survival and reproduction. Additionally, these contests are reliable signals of strength and endurance, allowing competitors to assess each other's capabilities without engaging in costly physical fights. Over time, natural selection will favour strategies that balance competition with self-preservation, ensuring the stability of displays within populations.

PREFACE ON GAME THEORY

J. Maynard Smith highlighted two main general points in the introduction to his article, as they provide the clarification on the reason why the mathematical concept of ESS is applied in animal displays:

1. Strategies are naturally selected to maximize the utility (or fitness) of the players.
2. Since natural selection acts throughout time, the solution must have the form of an ESS.

A step back to Game Theory's fundaments must be taken, for in this section I intend to provide all the basic knowledge of Game Theory deemed useful and necessary to understand the following examinations in later chapters.

As the Stanford Encyclopaedia of Philosophy writes: *"Game theory is the study of the ways in which interacting choices of economic agents*[6] *produce outcomes with respect to the preferences*[7] *(or utilities) of those agents, […].", where:*

The fundamental basis of Game Theory is the *"game"* (as the name anticipates), whose definition is close to the one suggested by common sense. Specifically, a game is described by three key components:

1. *Players*, or participants, who interact in groups of 2 or more.
2. *Strategies*, defined as the options to play available for each player, whose set is called action space.
3. *Payoffs*, which are the outcomes for each player and depend on the strategies played by **all** the participants, thus the definition of "interacting".

[6] denotes how each agent's optimal choice depends on the choices of the others.
[7] numerical values are assigned to each preference indicating the level of satisfaction of the agent, which allows for mathematical studies to be conducted.

A game is often represented with the help of a matrix, which plots each player's payoff for each combination of strategies played (a graphical example is illustrated after). This schematic way of illustration is helpful to immediately catch some properties or equilibriums in the game. For example, a "symmetric" game is a game in which the identity of the players does not matter, as their play under the same exact circumstances. They have the same set of strategies and receive the same payoff for any pair of strategies played: describing the specifics of one player is equivalent of explaining those of the second player. For example, if agent 1 plays strategy A and agent 2 plays B, with respectively payoff 1 and 2, if the two agents swap their strategies, their payoff is also swapped, but still identical: disregarding the player, strategy A against B receives 1, and strategy B against A receives 2. Graphically, a game is symmetric when the matrix of the payoffs of player 1 is that of player 2 but transposed (as in the Rock, Paper, Scissors game presented later). This is one of the easiest characteristics of a matrix to recognise, and it permits mathematicians to study the game more efficiently, employing the respective methodologies. Another important and time-saving technique is the elimination of strictly dominated strategies. A strategy is strictly dominated by another when, disregarding the behaviour of other players, its payoff are always lower than the other ones, no matter what. This way, a rational player will never choose such strategy since they can always increase their payoff by changing unilaterally their behaviour (a clear example is provided in "Human conflicts: the war of deterrence"). Indeed, it must not be forgotten that the aim of any player is to achieve the highest possible profit, given their opponents' choices.

Due to the interacting feature of games, it is often[8] possible to achieve a stable condition from where no player has an incentive to deviate, that is to change its strategy.

The second core element of Game Theory is indeed the *Nash Equilibrium:* defined as a set of strategies (one for each player in the game) such that no player can improve their payoff by unilaterally changing their strategy, given the strategies chosen by the other players. In other words, a profile of strategies is a NE if they are each other's best response. Its economic interpretation is quite relevant, as the NE indicates the situation(s) toward which a game economically and naturally converges, and that once reached, it is stable, unless perturbations are introduced in the game.

[8] The term "often" refers to the pure strategy case, as it is suggested by reason, where each player chooses a strategy to play with probability 1, that is with certainty. The mixed strategy case instead, implies that each strategy is assigned a specific probability to be played, whose sum equals 1. Unlike the pure strategy case, an important result in Game Theory is that a NE always exists in the mixed strategy due to the mathematical completeness of probability distribution.

The Rock, Paper, Scissors example is often presented as an easily accessible explanation of the difference between Nash Equilibria in pure and mixed strategy.

ROCK, PAPER, SCISSORS

As a brief recall, the game is played by two contestants who at each round can choose to play rock, paper o scissors with the corresponding gesture of their hands:

- rock wins against scissors but loses with paper.
- paper wins against rock but loses with scissors.
- scissors win against paper but loses with rock.

It follows a formal description of the game according to Game Theory costumes.

(P_1, P_2) the set of players, respectively player 1 and player 2.

$\Omega_1 = \Omega_2 = \{R, P, S\}$ the set of strategies of the players, in order rock, paper and scissors.

Games are illustrated through matrices, when possible, where the rows are the set of strategies of the first player, and the columns that of the second player. This way each cell reports the payoffs of the two players separated by a comma when the corresponding strategies are played.

$$\begin{array}{c} \\ R \\ P \\ S \end{array} \begin{array}{c} \begin{array}{ccc} R & P & S \end{array} \\ \begin{bmatrix} 0,0 & -1,1 & 1,-1 \\ 1,-1 & 0,0 & -1,1 \\ -1,1 & 1,-1 & 0,0 \end{bmatrix} \end{array}$$

Where the numerical value of 1 is assigned in case of victory, -1 in case of loss and 0 when parity occurs. This is a clear example of a symmetric game, where the two players' specifics are completely superimposable and interchangeable. Indeed, the payoff of player 1 when playing R against P is the same of that of player 2 when playing R against P: -1.

In pure strategy, contestants can only play one strategy for certain, but for the payoffs of the game, there exists no NE. Here is a graphical illustration of the endless loop which prevents any NE to establish:

$$\begin{array}{cc} & \begin{array}{ccc} R & \quad P & \quad S \end{array} \\ \begin{array}{c} R \\ P \\ S \end{array} & \begin{bmatrix} 0,0 & -1,1 & 1,-1 \\ 1,-1 & 0,0 & -1,1 \\ -1,1 & 1,-1 & 0,0 \end{bmatrix} \end{array}$$

Starting from (R, S), player 2 is willing to play P in spite of the higher payoff and makes the game shift to (R, P), then player 1 is willing to play S thus (S, P), then again player 2 is not satisfied and will move to (S, R) and so on.

In pure strategy, at least one player is never satisfied with the outcome and would be willing to change its strategy, thus there can't be any NE. Indeed, it also can be noticed that no strategy is strictly dominated by any other, as each strategy might prove useful to increase the payoff in response to a certain strategy played by the opponent.

In mixed strategy, each player chooses a strategy randomly, with probabilities between 0 and 1. The standard procedure for finding a NE involves applying the indifference principle, which states that each player's payoff must not vary as the strategy chosen by the other player changes. This ensures that no player has an incentive to deviate, and the expected payoff remains constant. The following computation helps in the understanding.

Consider the following set of probabilities played by both the players (as the numeric finding is irrelevant for our purposes):

$\left(p_1(R), p_1(P), p_1(S)\right) = \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)$ player 1 set of probabilities

$\left(p_2(R), p_2(P), p_2(S)\right) = \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)$ player 2 set of probabilities

$\mathrm{E}_1(\mathrm{R}) = \frac{1}{3}0 + \frac{1}{3}1 + \frac{1}{3}(-1) = 0$ the expected payoff of player 1 when player 2 plays R (look at the green box in the picture)

$E_1(P) = \frac{1}{3}(-1) + \frac{1}{3}0 + \frac{1}{3}1 = 0$ when player 2 plays P

$E_1(S) = \frac{1}{3}1 + \frac{1}{3}(-1) + \frac{1}{3}0 = 0$ when player 2 plays S

As the computations report, the expected payoff of player 1 if he plays with probabilities $\left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)$ is indifferent of the strategy played by player 2. The same is valid for player 2's expected payoff. Therefore, $\left\{\left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right), \left(\frac{1}{3}, \frac{1}{3}, \frac{1}{3}\right)\right\}$ is a NE.

The final core concept in Game Theory to introduce is the Evolutionarily Stable Strategy or ESS. When perturbations are introduced in the game, such as the emergence of rare or alternative strategies, it might become economically significant to verify whether the existing NE would remain stable over time or be outcompeted by any other pair of strategies. According to the formal definition *"A mixed strategy σ is an Evolutionary Stable Strategy if:*

- *for any pure strategy x:*

  $f(x, \sigma) \leq f(\sigma, \sigma)$, *where the expected payoff of strategy x played against σ is lower or equal to the expected payoff of σ played against itself. Thus, no pure strategy bests out the mixed one.*

- $x \in BR_1(\sigma)$ *and* $\sigma(x) < 1$ *, then:*

  $f(x, x) < f(\sigma, x)$*."*[9] In simple terms, if the pure strategy x is the best response to sigma and it is played in sigma with a probability lower than 1, the expected payoff of x played against itself is still lower than the payoff of σ played against x.

The definition assures that there is no existing or incoming strategy that could ever overcome the evolutionary stable one(s) considering all the possible cases. To ensure a correct and robust analysis of the ESS, the procedure can be written under the form of an algorithm[10].

The algorithm involves three steps:

- **Step 1:** Check that the strategy[11] is a NE, and it is symmetric. These two initial conditions deserve further explanations, since their understanding is not trivial at first glance, but fundamental to comprehend the logic of the algorithm and the ESS concept itself. Whenever a strategy is not an ESS, there must exist then another strategy that leads the player to a higher payoff. As a consequence, any strategy that is not a NE can never be an ESS, as it is not stable

[9] Xavier, V. (2024) Games & Strategies [ESS and correlated equilibrium] LUISS.
[10] The algorithm was designed by the professor V. Xavier as a teaching aid.
[11] We refer to one strategy as under symmetry the pair of strategies that define a NE is made by the same one adopted by both players.

even for the player itself (not to mention an entire population!). Furthermore, a NE must also be symmetric, meaning that all the players adopt the same strategy. This ensures that the population behaves uniformly, which is essential when studying the effects of a new invading strategy. Without this uniformity, it would be meaningless to analyze how a mutant interacts with the rest of the population. From this point on, the population strategy which is being studied for the ESS is defined as σ, and the mutant strategy as x. Only after having studied σ against all the possible mutant strategies x, it can be stated whether σ is evolutionary stable or not.

- **Step 2:** Investigate each pure strategy throughout all the different cases. The aim is to analyze whether a new mutant strategy would lead to a higher payoff or not. If no strategy can be found that improves the payoff, then the NE is said to be evolutionary stable.
    - *Case 1:* $\mathrm{P}(x) = 1$ the pure strategy is played with probability 1 under σ. It is the case in which the mutant plays the very same strategy of the population; thus no invasion is recorded.
    - *Case 2:* $\mathrm{f}(x, \sigma) < \mathrm{f}(\sigma, \sigma)$ the pure strategy is giving a lower payoff than the payoff at the equilibrium. The mutant strategy gains a lower payoff against the population than the population strategy against itself.
    - *Case 3a:* $\mathrm{f}(x, \sigma) = \mathrm{f}(\sigma, \sigma)$ and $\mathrm{f}(\sigma, x) > \mathrm{f}(x, x)$ the pure strategy is giving a good payoff against σ, but x against itself performs poorly. Even if the mutant strategy performs good enough against the population strategy, when playing against itself it is bested out by the population strategy.
    - *Case 3b:* $\mathrm{f}(x, \sigma) = \mathrm{f}(\sigma, \sigma)$ and $\mathrm{f}(\sigma, x) \leq f(x, x)$ the opposite case. Where the mutant strategy performs good enough to overcome in the long run or to be at least equivalent to the population strategy.
- **Step 3:** Draw the conclusion, if there is at least one Case 3b in the analysis, then the mixed strategy σ is not an ESS. Indeed, the Case 3b is the only case in which the population strategy performance is beaten by a mutant one.

ROCK, PAPER, SCISSORS CONT'D

Let's find the ESS, if it exists, applying the algorithm.

- **Step 1:**

$\left\{\left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right),\left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right)\right\}$ is the only symmetric (as the strategy is identical for both players) NE in the game, thus: $\sigma = \left\{\left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right)\right\}$. We shall test now if the NE is an ESS as well, investigating the comparison with each of the pure strategy R, P or S in the game.

Let's start from the pure strategy $x = R$:

- **Step 2:**
  - *Case 1:* $\mathrm{P}(R) = \frac{1}{3}$ in σ, so we shall proceed with the next case as the first condition is not met.
  - *Case 2:* $\mathrm{f}(R,\sigma) < \mathrm{f}(\sigma,\sigma)$, where:

    $\mathrm{f}(R,\sigma) = 0 \cdot \frac{1}{3} + (-1) \cdot \frac{1}{3} + 1 \cdot \frac{1}{3} = 0$, where player 1 plays R and player 2 plays $\sigma = \left\{\left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right)\right\}$ and

    $\mathrm{f}(\sigma,\sigma) = 0 \cdot \frac{1}{3} \cdot \frac{1}{3} + (-1) \cdot \frac{1}{3} \cdot \frac{1}{3} + 1 \cdot \frac{1}{3} \cdot \frac{1}{3} + 1 \cdot \frac{1}{3} \cdot \frac{1}{3} + 0 \cdot \frac{1}{3} \cdot \frac{1}{3} + (-1) \cdot \frac{1}{3} \cdot \frac{1}{3} + (-1) \cdot \frac{1}{3} \cdot \frac{1}{3} + 1 \cdot \frac{1}{3} \cdot \frac{1}{3} + 0 \cdot \frac{1}{3} \cdot \frac{1}{3} = 0$, where both players play $\sigma = \left\{\left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right)\right\}$.

    Since $\mathrm{f}(R,\sigma) = (\sigma,\sigma)$ we proceed to case 3.

  - *Case 3a:* $\mathrm{f}(\sigma,R) > \mathrm{f}(R,R)$:

    $\mathrm{f}(\sigma,R) = 0 \cdot \frac{1}{3} + 1 \cdot \frac{1}{3} + (-1) \cdot \frac{1}{3} = 0$, and

    $\mathrm{f}(R,R) = 0 = \mathrm{f}(\sigma,R)$, thus, the condition is not met.

  - *Case 3b:* Whenever none of the above conditions is met, it is surely Case 3b, indeed: $\mathrm{f}(R,R) = \mathrm{f}(\sigma,R)$
- **Step 3:** The game is symmetrical, therefore there is no need to investigate also for $x = P$ or $x = S$, as we would get the exact same results. Since there is a Case 3b, the strategy $\sigma = \left\{\left(\frac{1}{3},\frac{1}{3},\frac{1}{3}\right)\right\}$ is not an ESS.

THE MODEL

The model explores animal behaviour in displays and highlights how stability arises both from the payoff of the strategy itself and the resilience against perturbations introduced by rare or mutant strategies. The research is carried out with the aim of finding a general truth about the mechanisms in the evolution of populations and will serve as a fundament for the subsequent article "The Logic of Animal Conflict" (discussed later), where complementary and insightful conclusions are developed on animal behaviour and their strategies for survival.

The game defined by Maynard Smith happens to be officially published in 1974, when Game Theory was only at its first stages towards becoming a fundament of interdisciplinary research. Considering the above, here it follows a personal attempt to redefine the game under modern terms, with the sole scope of giving a more detailed and technical illustration of the results exposed in Maynard's article and provide a clearer reader's experience.

ON FINDING THE GAME

Each display, by definition, involves two animals engaging in a duel for a variety of possible reasons. According to the rules of nature, the animal who can endure longer ultimately wins the clash. The setting must now be translated into modern Game Theory terms, to enable an accurate analysis of all the potential strategies and their respective outcomes.

The game is set between two players, P_1 and P_2, with respective moves A and B. The two contestants can play any positive real number m_1 and m_2.

$$\begin{cases} A \in \mathbb{R}_+, m_1 \\ B \in \mathbb{R}_+, m_2 \end{cases}$$

According to the rules of the game, the victory is assigned to the contestant who plays the higher m, therefore, in case of parity there's a fifty percent of chance to win for each player. The utility functions of the two players are the following:

$$u_1(m_1, m_2) = \begin{cases} -m_1, m_1 < m_2 \\ \frac{1}{2}v - m_1, m_1 = m_2 \\ v - m_2, m_1 > m_2 \end{cases} \qquad u_2(m_1, m_2) = \begin{cases} -m_2, m_2 < m_1 \\ \frac{1}{2}v - m_2, m_2 = m_1 \\ v - m_1, m_2 > m_1 \end{cases}$$

where a contestant wins the victory gain v discounted by the amount of effort put in place until the other player is defeated $m_2(m_1)$, and loses the amount of effort until he is defeated $m_1(m_2)$.

The game is classified as symmetric, according to its identical strategies and payoffs for both the players. As a direct consequence, any strategic choice made by one player is equally valid for the other. This symmetry might be looked like an indicator of fairness, but in our game, it might lead to some implications instead. Specifically, the ambivalence of strategies might result in an infinite loop where every "winning" strategy is bested out by itself, thus preventing the game from reaching a stable equilibrium at least in pure strategy.

Indeed, we shall proceed by identifying all the Nash Equilibria of the game and verifying whether our deductions align with the outcomes.

NE IN PURE STRATEGY

The NE in pure strategy is strategically defined as (m_1^*, m_2^*) where m_1^* *and* m_2^* are each other's best response (BR), recalling that the NE is the stable condition from which no player has incentive to deviate:

$$\begin{cases} m_1^* = BR(m_2^*) \\ m_2^* = BR(m_1^*) \end{cases}$$

To find, if it exists, such equilibrium, we shall now consider three different cases according to the values of v, m_1^* and m_2^*:

1. $v > 0$,
    1. with $m_1^* < m_2^*$:
        1. for $0 \leq m_1^* \leq m_2^*$,

            then m_1^* *is never the best response to* m_2^*, since player 1 is going to lose the game for having played a lower value than 2. Therefore, player 1 has the profitable deviation to play zero to avoid the loss of $-m_1^*$, which opens for the following scheme:

        2. for $0 = m_1^* \leq m_2^*$,

            where a possible profitable deviation opens for player 2, who can play $m_2^{*\prime} = \frac{m_2^*}{2}$ (or whatever value lower than m_2^**) and still win the game, with lower efforts and higher gain* $v - m_2^{*\prime}$. Since for player 2 there's always a lower number they can play and still win the game (recall $B \in \mathbb{R}_+$), there exists no stable equilibrium NE.

    2. with $m_1^* > m_2^*$:

the same reasoning applies as before, where players take each other's position.

3. with $m_1^* = m_2^*$:
   1. for $\left(\frac{1}{2}v - m\right) < 0$,

      which implies negative returns also for the winner, player 1 should play 0, thus not participating in the game.

   2. for $\left(\frac{1}{2}v - m\right) > 0$,

      two possible deviations open:

      - $m_1^{*\prime} < m_1^*$, where player 1 loses the game from the parity position and such deviation is not profitable, indeed their utility would move from $\left(\frac{1}{2} - m_1^*\right) > 0$ *to* $-m_1^{*\prime} < 0$.
      - $m_1^{*\prime} > m_1^*$, where player 1 wins with cost $m_1^{*\prime} \approx m_1^*$ and gain $(v - m_2^*) > \left(\frac{1}{2}v - m_2^*\right)$. The deviation ε, where $m_1^{*\prime} = m_1^* + \varepsilon$, is profitable for each: $v - (m_1^* + \varepsilon) > \frac{1}{2}v - m_1^*$, which translates into $\varepsilon < \frac{1}{2}v$. The same profitable deviation opens for player 2, thus each of the two player has an incentive to deviate toward a higher m until $\varepsilon = \frac{1}{2}v$. Again, there is no NE since the interval $0 < \varepsilon < \frac{1}{2}v$ contains infinite numbers in $\mathbb{R}_+$.

2. $v = 0$,

   both players have no incentive to play and will therefore never enter the competition, since for any number they play their payoff would be negative. Their choice is respectively $m_1^* = 0$ *and* $m_2^* = 0$: this is a pure NE.

3. $v < 0$,

   Same reasoning as in (2) applies.

We can conclude that *only if v is purely positive there is no NE in pure strategy,* where each profitable deviation strategy can be bested out by itself. As in nature v is often strictly positive in duels, concerning food, reproduction or many other reasons, we shall explore our game further in the mixed strategy.

NE IN MIXED STRATEGY

The Nash Equilibrium in mixed strategy can be found by the indifference principle, recalling that for such principle players are indifferent between their strategies, since they need to yield the same expected payoff. In mathematical terms, it can be expressed as:

$u_2(p(x), m) = \lambda$, where

λ is the constant value associated with the utility function u_2 of player 2. The first input of the function is the mixed strategy $p(x)$, representing the probability distribution of player 1's choices, (in simple terms, player 1 plays a certain value x with probability $p(x)$). The second input is the parameter m, which represents player 2's strategy. The goal is to determine the value of $p(x)$ that satisfies the condition of indifference mentioned above.

Exploiting player 2's utility function, given m one has:

$$u_2(p, m) = \int_x u_2(x, m)p(x)\ dx = \mathrm{E}\big(u_2(x, m)\big)$$

$$u_2(p, m) = \int_0^m (v - x)p(x)\ dx + \int_m^m \left(\frac{1}{2}v - m\right) p(x)\ dx + \int_m^{+\infty} -mp(x)\ dx$$

The first integral represents the case for any $x < m$ where player 2 wins $(v - x)$, the second describes the case in which players are in a condition of parity and both play exactly m (or x equivalently), and the latter formalises the case $x > m$ where player 2 loses $-m$. Note that the second integral, under the assumption $P(x = C) = 0$ in $\mathbb{R}_+$, is equal to zero.

After some arrangements:

$$\mathrm{v} \int_0^m p(x)\ dx - \int_0^m xp(x)\ dx - \mathrm{m} \int_m^{+\infty} p(x)\ dx = \lambda$$

We shall now compute the first derivative with respect to m and set it equal to zero (or First Order Condition), as the result will be exactly the value of $p(x)$ for which u_2 is constant:

$$\frac{\partial u_2}{\partial \mathrm{m}} = 0$$

$$\mathrm{vp}(m) - \mathrm{mp}(m) - \left(\int_m^{+\infty} p(x)\ dx - mp(m)\right) = 0$$

$$\mathrm{vp}(m) - \int_m^{+\infty} p(x)\ d\mathrm{x} = 0$$

$$\mathrm{vp}(m) = \int_m^{+\infty} p(x)\ d\mathrm{x}$$

As the function cannot be further exploited, we shall proceed further with the second derivative to find the zero:

$\mathrm{v}\frac{\partial p(m)}{\partial m} - \mathrm{p}(m) = 0$, which has solution

$\mathrm{p}(m) \propto e^{-\frac{m}{v}}$, or equivalently $\mathrm{p}(m) = \mathrm{c}e^{-\frac{m}{v}}$

We generalize by replacing m with x since m is just a placeholder variable, and the functional form $p(m)$ applies to the entire domain of the distribution $p(x)$:

$$\mathrm{p}(x) = ce^{-\frac{x}{v}}$$

Then, to find that constant c which represents only one among the possible solutions, we shall provide for the condition of normalization in the computations, according to which the total probability of all possible outcomes must equal 1:

$$\int_0^{+\infty} ce^{-\frac{x}{v}}\ d\mathrm{x} = 1$$

$$\mathrm{c}\int_0^{+\infty} e^{-\frac{x}{v}}\ d\mathrm{x} = 1$$

$$\mathrm{c}\left[-ve^{-\frac{x}{v}}\right]_0^{+\infty} = 1$$

$$\mathrm{c}\left[\lim_{x\to+\infty} -ve^{-\frac{x}{v}} - \left(-ve^{-\frac{0}{v}}\right)\right] = 1$$

$$\mathrm{c}(0 + v) = 1$$

$\mathrm{c} = \frac{1}{v}$, finally, we plug in the result for $p(x)$:

$$\mathrm{p}(x) = \frac{1}{v}e^{-\frac{x}{v}}\ [1]$$

The NE is attained at the symmetric equilibrium where both players play $p(x) = \left(\frac{1}{v}e^{-\frac{x}{v}}\right)$.

Once we get the value of $p(x)$ is a good costume to counter check that player 1, for any value of x he chooses to play, gets the same payoff against player 2, as previously we only looked for player 2's indifference:

$$u_1 = \int_0^x (v-m)p(m)\ \mathrm{dm} + \int_x^x \left(\frac{1}{2}v - m\right)p(m)\ \mathrm{dm} + \int_x^{+\infty} -xp(m)\ \mathrm{dm} =$$

$$= \int_0^x (v-m)\frac{1}{v}e^{-\frac{m}{v}}\ \mathrm{dm} + \int_x^{+\infty} -x\frac{1}{v}e^{-\frac{m}{v}}\ \mathrm{dm} =$$

$$= \int_0^x e^{-\frac{m}{v}}\ \mathrm{dm} + \int_0^x -\frac{m}{v}e^{-\frac{m}{v}}\ \mathrm{dm} - \mathrm{x}\int_x^{+\infty}\frac{1}{v}e^{-\frac{m}{v}}\ \mathrm{dm} =$$

$$= \int_0^x e^{-\frac{m}{v}}\ \mathrm{dm} + \left[me^{-\frac{m}{v}}\right]_0^x - \int_0^{\mathrm{x}} e^{-\frac{m}{v}}\ \mathrm{dm} - \mathrm{x}\left[-\frac{1}{v}ve^{-\frac{m}{v}}\right]_x^{+\infty} =$$

$$= \left[me^{-\frac{m}{v}}\right]_0^x - \mathrm{x}\left[-e^{-\frac{m}{v}}\right]x^{+\infty} =$$

$$= \mathrm{x}e^{-\frac{x}{v}} - \mathrm{x}e^{-\frac{x}{v}} =$$

$$= 0$$

As it states out from the computations, the utility is completely independent of the value v the players can win. The obtained value of zero might seem odd at first, instead two relevant facts must be brought into light:

1. The strategy $x = 0$, whose payoff is null, is included in the set. And therefore, player 1 can be indifferent among all the possible values of x only if $u_1 = 0$ in the end.
2. The oddity might come first from a misinterpretation of the utility. As Maynard highlights: *"The advantage that the winner of such a contest has over the loser is to be measured not by the energy in the food obtained, but by the energy which the loser must expend in finding a second similar item of food."*[12].

Lastly, we shall verify whether the Nash Equilibrium is stable throughout the time, thus it's an ESS.

[12] J. Maynard Smith "The theory of Games and the Evolution of Animal Conflicts"

The ESS in game theory is defined as the strategy for which the expected utility of such strategy played against himself is higher than the utility of any other strategy played against it. Only if such condition realises, then the strategy is stable and unaffected by other incoming behaviours. In natural terms, if the strategy of a specific male buffalo during reproduction duels qualifies as an ESS, and no other complicating factors subsist, then he will consistently win over any rival bull buffalo he encounters, even those from distinct or newly formed packs. To emphasize, if his strategy were merely a NE no conclusions could be drawn a priori about the moose's ability to win against specimen from other packs than the one analyzed.

To verify the ESS condition, we introduce a strategy σ that plays one positive real number ς, opposed to the mixed strategy X that plays $p(x)$. The idea is to test whether the strategy $p(x)$ yields the highest payoff for the player, regardless of the opponent's strategy. In other words, $p(x)$ shall persist as NE despite any new or rare strategy opponents might introduce in the game.

Thus, we shall demonstrate that for any positive unknown ς (given strategy σ) played by a contestant, the expected payoff of strategy X against σ is always higher than σ versus itself. Equivalently, $E_{p(x)}(\sigma) > E_{\sigma}(\sigma)$:

1. σ vs. σ:

   $E_{\sigma}(\sigma) = \frac{1}{2}\mathrm{v} - \varsigma$, recall the $m_1 = m_2$ case.

2. $p(x)$ vs. σ:

   $E_{p(x)}(\sigma) = \int_0^{\varsigma} -xp(x)\ dx + \int_{\varsigma}^{\varsigma} \left(\frac{1}{2}v - \varsigma\right) p(x)\ dx + \int_{\varsigma}^{+\infty} (v - \varsigma)p(x)\ dx$, where [1]

   $= \int_0^{\varsigma} -x\frac{1}{v}e^{-\frac{x}{v}}\ dx + \int_{\varsigma}^{+\infty} (v - \varsigma)\frac{1}{v}e^{-\frac{x}{v}}\ dx =$, integrating by parts we obtain

   $= \left[xe^{-\frac{x}{v}}\right]_0^{\varsigma} - \int_0^{\varsigma} e^{-\frac{x}{v}}\ dx + (v - \varsigma)\frac{1}{v}\int_{\varsigma}^{+\infty} e^{-\frac{x}{v}}\ dx =$

   $= \left[xe^{-\frac{x}{v}} + ve^{-\frac{x}{v}}\right]_0^{\varsigma} + (v - \varsigma)\frac{1}{v}\left[-ve^{-\frac{x}{v}}\right]_{\varsigma}^{+\infty} =$

   $= \varsigma e^{-\frac{\varsigma}{v}} + \mathrm{v}e^{-\frac{\varsigma}{v}} - \mathrm{v} + e^{-\frac{\varsigma}{v}}(v - \varsigma) =$

   $= e^{-\frac{\varsigma}{v}}(\varsigma + v + v - \varsigma) - \mathrm{v} =$

$= 2ve^{-\frac{\varsigma}{v}} - \mathrm{v}$

Let’s verify the condition for $p(x)$ to be an ESS by verifying whether $E_{p(x)}(\sigma) > E_{\sigma}(\sigma)$:

$2ve^{-\frac{\varsigma}{v}} - \mathrm{v} > \frac{1}{2}\mathrm{v} - \varsigma$, where $\varsigma \geq 0$ as assumption

$\mathrm{v}\left(2e^{-\frac{\varsigma}{v}} - 1 - \frac{1}{2}\right) \succ -\varsigma$

$2e^{-\frac{\varsigma}{v}} - \frac{3}{2} \succ -\frac{\varsigma}{v}$

$2e^{-\frac{\varsigma}{v}} + \frac{\varsigma}{v} - \frac{3}{2} > 0$, where $\gamma = -\frac{\varsigma}{v}$

$2e^{-\gamma} + \gamma - \frac{3}{2} > 0$

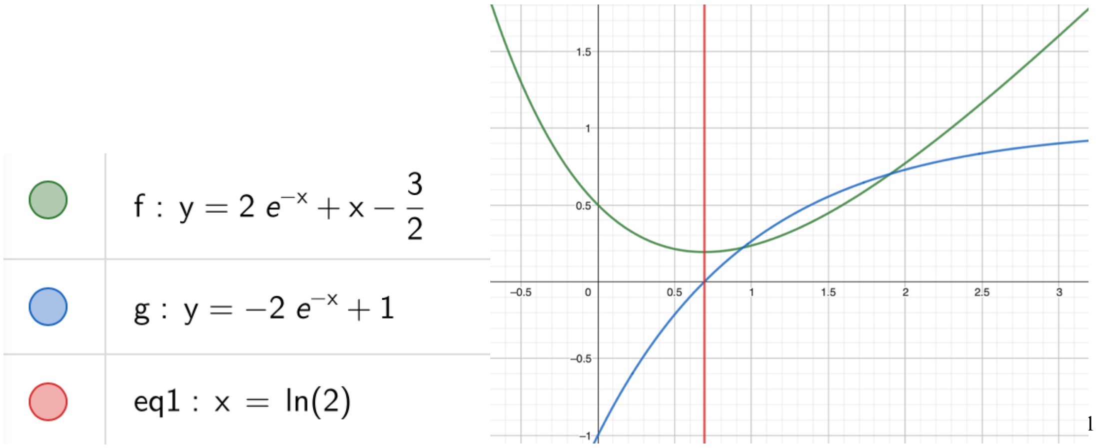
Now let’s study the function to understand whether it’s always strictly positive:

With the table of variation, we can study the behaviour of the function at its limits:

1. For $\gamma \to -\infty$: $\mathrm{f}(\gamma) \to +$;
2. for $\gamma = 0$: $\mathrm{f}(\gamma) = \frac{1}{2}$;
3. for $\gamma \to +\infty$: $\mathrm{f}(\gamma) \to +$.

At its limits the function approaches $+\infty$, accordingly if its lowest value is positive, the function must always be strictly positive. We shall proceed by finding its minimum with the First Order Condition (FOC):

$\mathrm{f}'(\gamma) = -2e^{-\gamma} + 1 = 0 \to \gamma = ln(2)$ and $\mathrm{f}(\gamma) \approx 0.19 > 0$



[13]

We can conclude that our function is always strictly positive and that, finally, $\mathrm{p}(x) = \frac{1}{v} e^{-\frac{x}{v}}$ [1] is the ESS of the game in mixed strategy.

CONCLUSIONS

As Maynard concludes *"an evolutionarily stable population is either genetically polymorphic[14], the strategies of individuals being distributed as in [1], or that it consists of individuals whose behaviour differs from contest to contest as in [1]. There is no stable pure strategy, and hence no behaviourally uniform population[15] can be stable."*[16]

In simple terms, a population that consists solely of specimen adopting a single pure strategy is highly exposed to invasion by another species or pack, as stated by the pure strategy attempt. Instead, a population who adopts different pure strategies x with frequences $\mathrm{p}(x) = \frac{1}{v} e^{-\frac{x}{v}}$, or where everyone adopts a mixed strategy and behaves differently accordingly to the contest, allows for flexibility and adaptability, reaching a long-term equilibrium.

CONTINUATIONS

Previous analyses have focused on conflicts between animals where no injury at all could be inflicted and victory was assigned to the contestant prepared to endure the longest. In such contests strategies are shaped by persistence and the ability to sustain effort. However, when offensive weapons and potential escalation are introduced in the game the dynamics of contests change fundamentally. Victory is no longer solely determined by endurance, but also by the capacity to inflict or avoid injury, making escalation a critical factor in the outcome.

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[13] Made with Geogebra.org
[14] A population capable of adopting different strategies.
[15] A population adopting a single pure strategy.
[16] J. Maynard Smith "The theory of Games and the Evolution of Animal Conflicts"

Maynard Smith and Price in *"The Logic of Animal Conflict"* of 1973 demonstrated that in contexts where escalated fighting is possible, an ESS must account for both the benefits of escalation and its associated costs, such as the risk of injury or death. The stability of a strategy then depends on its ability to balance these trade-offs efficiently. For instance, a species employing a retaliatory strategy, who escalates only in response to an opponent's escalation, might achieve a stable equilibrium, deterring excessive aggression while minimizing the risk of mortal injuries.

THE LOGIC OF ANIMAL CONFLICT

INTRODUCTION

The work will then proceed with a modern reinterpretation of Maynard Smith's 1973 paper, offering an alternative approach to identifying the ESS when accounting for the possibility of injury. A fully developed fictitious model has been constructed, allowing for the observation of the ESS and how it shifts in response to changes on the initial conditions. Finally, a broader comparison will be drawn with human behavior in conflicts, examining how the model predicts the deterrence war and the survival of nations. This analysis will focus on the strategic interactions of the world's two most powerful rivals, discovering the evolutionary principles that govern large-scale competition.

THE PREFACE

When conflicts between animals of the same species occur, the range of strategies that might be adopted are usually of a *limited war* kind, that is they are usually tournaments rather than displays where no serious injury is typically inflicted. In most competitive encounters, where food, territory or reproduction is at stake, one might expect animals to adopt the most effective weapons and fighting styles in a fight to the death (*total war*). Yet, in nature we observe how animals persevere in fighting with limited-war strategies. How can one explain this at first glance paradox?

Recalling what already stated in the introduction, one early explanation offered by Huxley explains that nature tends to preserve the species avoiding dangerous behaviours that would militate against survival; thus, it operates under the principle of "group selection". However, this reason seemed not enough to Maynard and Price to fully account for animal behaviour. Instead, they proposed that there must be also an individual benefit alongside group selection that leads animals to opt for limited war.

To support their hypothesis, they constructed a computer-based model to simulate conflicts and collect data with the aim of analysing whether the limited-war strategy is beneficial to individuals as well rather than only species. Specifically, by determining if a retaliator strategy has the characteristics of an ESS compared to other possible behaviours.

THE MODEL

For the development of the model the authors constructed a rather peculiar and innovative computer-based procedure for their time. It is based under a simple yet efficient rationale: a simulation of an indefinite number of encounters between animals capable of inflicting serious injuries adopting different strategies is carried on testing whether escalation to total war would result optimal, as logic might suggest.

The model incorporates two distinct tactics: "Conventional" denoted as C, which are unlikely to cause serious damages, and "Dangerous" or D for situations where serious injury is likely. Each strategy is characterized by a different use of C or D tactics, as the underlying logic and associated probabilities differ across species. Consequently, each encounter takes the following form:

A's move: C C C D C C C D

B's move: C C C D C C C R

In this example, individual A initiates the encounter with a conventional move which might inflict only a minor scratch to the opponent. Individual B responds in kinds for three times, after which A plays a dangerous tactic to provoke the opponent (or **probe**). In response, B uses a dangerous move too (or **retaliates**). After some conventional moves, lastly A escalates again, and B finally retreat (R) from the contest. At the end of each encounter, the payoffs are calculated and stored for subsequent statistical analysis.

For the computer simulation five different strategies are assumed, where *"A "strategy" for a contestant is a set of rules which ascribes probabilities to the C, D and R plays, as functions of what has previously happened in the course of the current contest."*[17] and each strategy might be suggested by logic as an optimal strategy under specific circumstances:

1. *Mouse:* "Never plays D. If receives D, they retreat immediately before any possibility of being injured."[18] Otherwise, they play C until the contest lasts.
2. *Hawk:* Always plays D, until they are seriously injured or the opponent retreats.

[17] J. Maynard Smith & G. R. Price "The Logic of Animal Conflict"
[18] J. Maynard Smith & G. R. Price "The Logic of Animal Conflict"

3. *Bully:* Plays D when making the first move or in response to C. "Plays C in response to D and retreats after the opponent played D a second time."[19]
4. *Retaliator:* Plays C when making the first move or in response to C. If the opponent plays D, they retaliate by playing D.
5. *Prober-Retaliator:* In response to C, they play C with high probability and D with a low probability. After probating, they revert to C if the opponent retaliates, otherwise they continue playing D. After receiving a probe, they retaliate.

   For a total of fifteen different types of two opponent contests.

The *Hawk* strategy corresponds to what we have defined as "total war" so far, while the other strategies represent various forms of limited war. If Maynard and Price's thesis is incorrect, then the *Hawk* strategy will emerge as the evolutionarily stable strategy, indicating that limited war is driven solely by group selection. Conversely, if their thesis is correct, then one or more of the limited war strategies will prove to be evolutionarily stable equilibria.

As for the previous article, a personal attempt to rewrite the game in the modern approach of Game Theory follows in order to replicate the simulation and facilitate a comprehension of the results.

The probability distribution and payoff assignment criteria employed in the paper is the following:

- number of contests =2000.
- number of rounds for each contest =20.
- probability of serious injury after D is received =0.10.
- probability that Prober-Retaliator will probe after receiving C =0.05.
- payoff for winning =60.
- payoff for exiting the contest due to a serious injury = -100.
- payoff for each D received that it doesn't inflict serious damage (scratch) = -2.
- payoff for saving time and energy =20 (uniformly distributed on the number of rounds).

[19] J. Maynard Smith & G. R. Price "The Logic of Animal Conflict"

Table 1 Average Pay-offs in Simulated Intraspecific Contests for Five Different Strategies

		Opponent				
		"Mouse"	"Hawk"	"Bully"	"Retaliator"	"Prober-Retaliator"
Contestant receiving the pay-off	"Mouse"	29.0	19.5	19.5	29.0	17.2
	"Hawk"	80.0	−19.5	74.6	−18.1	−18.9
	"Bully"	80.0	4.9	41.5	11.9	11.2
	"Retaliator"	29.0	−22.3	57.1	29.0	23.1
	"Prober-Retaliator"	56.7	−20.1	59.4	26.9	21.9

Figure 1

In the table reported from the article, each number represents the average payoff assigned to the row strategy when played against the column strategy, for instance the average payoff of the *Hawk* when he encounters a Mouse is 60.

REPLICATION AND EXPLANATION OF THE MODEL

Here it follows a personal attempt to rewrite the payoffs in modern terms aiming to capture the mathematical formulas behind them, accounting for small deviations from the expected value that may arise due to sampling variation. Due to lacks in the original paper, it must be stressed that it is only an attempt to figure out the logic behind, and in the most difficult cases (mainly concerning prober-retaliators) a comparative approach has been used to get at least the intuition behind the authors' results. In the following script, the capital letter "E" stands for "expectation" (of the payoff), the subscript indicates the strategy we are computing the expectation for, and the capital letter in the square brackets is the strategy against our player is fighting:

- Mouse vs. Mouse: $E_M[M] = \frac{1}{2} \cdot 0 + \frac{1}{2} \cdot 60 = 30$

  Since two equal strategies are duelling against each other, in the case of two mice the contest will simply end by one of the two retreating. Thus, half of the times a mouse win and the other half leaves uninjured, without any reward for saving time as they retreat only at the end.

- Mouse vs. Hawk: $E_M[H] = 20$

  Any mouse when playing against a hawk will receive a payoff of 20, since they are retreating immediately (recalling hawks play always D) before any possibility of being injured. Their positive expectation is solely given by the whole time they save as the game stops at the first round.

- Mouse vs. Bully: $E_M[B] = 20$

In a match were a mouse and a bully fight each other, the payoff is the same as in the case Mouse vs. Hawk, since both hawks and bullies play D at the first round.

- Mouse vs. Retaliator: $E_M[R] = \frac{1}{2} \cdot 0 + \frac{1}{2} \cdot 60 = 30$

When a mouse encounters a retaliator, the same situation as two mice fighting each other will occur, since the retaliators always play C if not probed.

- Mouse vs. Prober-retaliator: $E_M[P] = 0.64 \cdot \left(\frac{20}{2}\right) + 0.36\left(\frac{1}{2} \cdot 60 + \frac{1}{2} \cdot 0\right) = 17.2$

For this match a peculiar approach has been used due to the complexity of the Prober-retaliator strategy. Since prober-retaliators probes after receiving C with 5%, it allows us to simplify the game into two scenarios:

1. The event that Prober-retaliator probes "X" never happened in 20 rounds: $P(X = 0) = 0.95^{20} = 0.36$.
2. The event that <u>at least once</u> the prober-retaliator has played D and the mouse left the contest: $P(X \geq 1) = 1 - 0.95^{20} = 0.64$.

In the former case, the pattern of Mouse vs. Retaliator repeats. In the latter case, the mouse leaves uninjured the contest and wins a positive amount for having saved time. Such quantity is proportional to the amount of time they save, thus on a basis of 20 rounds on average it happens at the tenth, which corresponds to the factor $\frac{20}{2}$.

- Hawk vs. Mouse: $E_H[M] = 60 + 20 = 80$

Since hawks always play D making the opponent retreat at the first round, they win the payoff for winning plus the time saved.

- Hawk vs. Hawk: $E_H[H] = \frac{1}{2}(60 + 14 + 2 \cdot 6) + \frac{1}{2}(-100) = -19$

When two hawks fight against each other always playing D, half of the times a hawk wins and the other half loses injured to death (-100), since D is lethal at 10% there's equal chances this event is going to benefit the first or the second player. The hawk who wins, is going to receive 60 plus a particular amount which should be further explained. The term "$14 + 2 \cdot 6$" is because hawks save 14 rounds by playing on average only the first 6, where they receive 2 each time after receiving but surviving to D (scratch). The intuition behind the fact that one of the two hawks is going to die on average round 6 is that each round both the players play D, with a total probability of $0.90^2 = 0.81$ that both survive. Thus, the probability that at least one hawk dies is $(1 - 0.81) = 0.19$, and the expectation (average) of such geometric random variable[20] is $\frac{1}{0.19} \approx 6$ by eccess.

- Hawk vs. Bully: $E_H[B] = \frac{1}{2}\big(0.10(60+20) + 0.90(60+19)\big) + \frac{1}{2}\Big(0.10(-100) + 0.90\big(0.10(60+20-2) + 0.90(60+19-2)\big)\Big) = 69.2$

  For some cases, it is important to consider who starts first and combining then the results, assigning to each a weight of 50% (or a half). If Hawk starts, there is a 10% of probability that Bully suffers a lethal damage, giving immediately a payoff of 60 plus 20 for the time saved to the hawk. Instead, the remaining 90% represents the scenario in which the attack is not lethal, the bully plays C in and, after playing the second D, finally the bully retreats before being injured. The hawk gains 19 for the time saved since the bully retreats during the second round. If Bully starts playing D, Hawk dies with a 10%, or survive and plays D, so the process described in the first half of the equation repeats, with the difference of a "-2" due to the scratch inflicted by the first move of the bully (if not lethal).

- Hawk vs. Retaliator: $E_H[R] > E_H[H]$

  To simplify this case, it is enough to understand that the expectation for a hawk against a retaliator is going to be slightly higher than a hawk against itself. It is a more favorable case since the retaliator never starts probing, it will always be the hawk who starts, after which both the players will play D for all the rounds. Thus, the probability that the hawk inflicts a deadly damage is slightly higher than the one of the retaliator, since the hawk makes always the first dangerous move.

- Hawk vs. Prober-retaliator: $E_H[H] < E_H[P] < E_H[R]$

  The expectation of a hawk vs a prober-retaliator collocates in between those of two hawks fighting and a hawk between a retaliator. The logic behind of this expectation being higher than E_H[H] is the same as the previous case. However, we must consider that a prober-

[20] A random variable X follows a Geometric distribution when, repeating an experiment independently many times, X represents the first round in which there is a success.

retaliator might start probing with a 5% of probability. This information makes the expectation being slightly lower than $E_H[R]$ at the same time, since (despite in a small number of encounters) the prober-retaliator might start probing, rising the chances of a Hawk to receive deadly injures.

- Bully vs. Mouse: $E_B[M] = E_H[M] = 80$

  Given mice always play C, bullies will behave exactly as hawks in this type of game by playing always D, receiving their same expected payoff.

- Bully vs. Hawk: $E_B[H] = \frac{1}{2}\big(0.10(-100) + 0.90(18-2)\big) + \frac{1}{2}\Big(0.10(60+20) + 0.90\big(0.10(-100) + 0.90(18-2)\big)\Big) = 8$

  The intuition behind is the same as in Hawk vs. Bully, but the point of view this time is that of the bully, who is going to retreat from the second time they receive D (when alive).

- Bully vs. Bully: $E_B[B] = \frac{1}{2}\big(0.10(60+20) + 0.90(60+19)\big) + \frac{1}{2}\big(0.10(-100) + 0.90(19-2)\big) = 42.2$

  When two bullies meet, the scheme is fixed: the first bully probes with D, receive C in response and probes again making the opponent retreat immediately. Consequently, half of the assigned payoff is from the bully who starts first, the other half from that who retreats. The first part of the equation represents the first bully who is going to win either at the first round for inflicting a deadly scar, or at the second when its opponent retreat. The second part stands for the second bully, who either dies at the first round or retreats at the second one.

- Bully vs. Retaliator: $E_B[R] = \frac{1}{2}\Bigg(0.10(60+20) + 0.90\Big(0.10(-100) + 0.90\big(0.10(60+17-2) + 0.90(16-2)\big)\Big)\Bigg) + \frac{1}{2}\Bigg(0.10(60+19) + 0.90\Big(0.10(-100) + 0.90\big(0.10(60+16-2) + 0.90(15-2)\big)\Big)\Bigg) = 14.8$

  Again, the equation is divided into two halves according to who is going to open the contest. If a bully starts, they have 10% of probability to win immediately the contest, otherwise the opponent will retaliate by playing D, lethal at 10%. If the bully survives, he plays C, and receive C as response since retaliators escalate only when probed. Then, Bully will now provoke again playing D, which will make him either win at the third round (17 for the time saved minus 2 for the scratch) or receive another D and finally retreating at the fourth before being injured (16 minus 2). The second half of the equation represents the same scheme shifted by 1 round, since the initial move C of the retaliator will make the game have the same pattern.

- Bully vs. Prober-retaliator: $E_B[P] < E_B[R]$

  This game is similar to the previous case, the only difference is that a prober-retaliator will play D even in response to a C with 5%. This information slightly lowers the expected payoff of the bully, due to the fact that there are more chances he might suffer a lethal damage.

- Retaliator vs. Mouse: $E_R[M] = E_M[M] = 30$

  Since mice never probe, the expected payoff is equal to the case Mouse vs. Mouse.

- Retaliator vs. Hawk: $E_R[H] = \frac{1}{2}\left(\frac{1}{2}(60 + 14 - 2 \cdot 6) + \frac{1}{2}(-100)\right) + \frac{1}{2}\left(\frac{1}{2}(60 + 13 - 2 \cdot 7) + \frac{1}{2}(-100)\right) = -20$

  When a retaliator fights against a Hawk the scheme is reminds that of two hawks against each other. Indeed, the first part is identical, since when the hawk starts both the players use dangerous moves. If the retaliator starts the pattern is shifted by one round but still identical: Hawk will respond with D to the first move C of his opponent, and from then on it is the same as the previous case.

- Retaliator vs. Bully: $E_R[B] = \frac{1}{2}\Big(0.10(-100) + 0.90\left(0.10(60 + 19 - 2) + 0.90\big(0.10(-100) + 0.90(60 + 17 - 2 \cdot 2)\big)\right)\Big) + \frac{1}{2}\Big(0.10(-100) + 0.90\left(0.10(60 + 18 - 2) + 0.90\big(0.10(-100) + 0.90(60 + 16 - 2 \cdot 2)\big)\right)\Big) = 41.5$

  The intuition behind is the same of the Bully vs. Retaliator case, but from the point of view of the retaliator.

- Retaliator vs. Retaliator: $E_R[R] = E_M[M] = 30$

  Since no one probes, players will never adopt dangerous weapons, thus behaving as two mice.

- Retaliator vs. Prober-retaliator: $E_R[P] < E_R[R]$

  The Prober-retaliator strategy is characterized by a high level of complexity with respect to the other strategies, thus it requires a more sophisticated approach. However, for the purpose of this thesis I deem not useful nor easy to explain the application of such methods. (For all the experts in the field, the payoff equation of the Retaliator when playing against a Prober-retaliator would exploit the Markov Chain stochastic process). Therefore, it is sufficient to understand how the comparative approach can be used to conclude that $E_R[P] < E_R[R]$. When a Prober-retaliator and a retaliator fight, the standard scheme is that of two retaliators against each other. But the Prober-retaliator can generate some deviations from the normal pattern as they probe with a 5% of probability. When it is the case, the encounter escalates as if two hawks were fighting, making the game end for a death rather than for round exhaustion. Therefore, the Retaliator's payoff is lower for two main causes:

  1. They might be the ones to die and receive a -100;
  2. Even if they win, the payoff is lowered by scratches (at least one) to which they survived.

- Prober-retaliator vs. Mouse: $E_P[M] = 0.64(60 + 10) + 0.36 \cdot 30 = 55.6$

  The same approach of Mouse vs. Prober-retaliator has been used to compute the probabilities of the scenario in which the prober retaliator never probes and of its counter event. In the first part the prober-retaliator gains a surplus for the time saved of 10 since we take the expected value at which the 5% of probing realises. In the last part the "30" is due to the expectation of a retaliator against a mouse (since prober-retaliator at 36% hasn't played D).

- Prober-retaliator vs. Hawk: $E_P[H] \approx E_R[H] = -20$

  Due to the complexity of accounting for the 5% of the prober-retaliator using aggressive weapons as first move, we can simplify to the case of Retaliator vs. Hawk. Indeed, the scheme is almost identical, the only difference stems from the fact that when doing the opening move a prober-retaliator might start playing dangerously with a 5%, which has an impact on the expectation small enough to be approximated to zero.

- Prober-retaliator vs. Bully: $E_P[B] > E_R[B]$

Following the same logic as in other fights were prober-retaliators are involved, the expectation is slightly higher than it is in the Retaliator case. Again, due to the 5% of probability of a prober-retaliator probing.

- Prober-retaliator vs. Retaliator: $E_P[R] > E_R[P]$

  The inequality stems from the fact that, since it is certain that only prober-retaliators could start playing dangerously, the chances of their attack being lethal (rather than their opponent's one) are in favor of prober-retaliators.

- Prober-retaliator vs. Prober-retaliator: $E_P[P] < E_R[P]$

  In this case, the payoff is lowered with respect to a Retaliator vs. Prober-retaliator game by the decrease in the probability that a game would end with a tie (as Mouse vs. Mouse). This time, both the players could start probing and the chances of the game escalating increase. As a consequence, it will happen more frequently that a fight ends for a deadly damage, reducing the expectation in the payoff.

This model calls for a slight different approach than usual when looking for the ESS given the way it was built. Unlike the theory imposes, in this case there is no need to look at NE first, since the authors make already such assumption, stating that *"[...] we programmed five possible strategies, each of which might be thought on a priori grounds to be optimal in certain circumstances."*[21]. Specifically, one must examine each column and interpret the numbers therein to assess the evolutionary stability of such strategy. The logic behind is that if a strategy is an ESS, no alternative strategy should yield a higher payoff against it than it does when played against itself. To make an example, in figure [1] the *Hawk* strategy is not an ESS, since when observing the *Hawk* column, the row strategy *Mouse* would obtain a higher payoff against *Hawk* than *Hawk* earns it against itself (as 19.5>-19.5). Thus, the *Hawk* strategy would be bested out by the *Mouse* strategy. According to this line of reasoning, the only ESS in figure [1] is the *Retaliator* strategy, with *Prober-Retaliator* being nearly an ESS. Consequently, one expects the population to evolve such that the other strategies remain at a low frequency, while *Retaliator* and *Prober-Retaliator* dominate. The balance between the two will be influenced by the frequency of strategy *Mouse*, given that probing is only an advantage against *Mouse*.

[21] J. Maynard Smith & G. R. Price "The Logic of Animal Conflict"

Finally, the simulations show that “limited war” strategies are beneficial for individuals as well. Even after excluding the possibility of group selection as the sole driver, such strategies remain evolutionarily stable, whereas the *Hawk* (or total war) strategy does not.

IMPLICATIONS

Real animal conflicts are vastly more complex than the simulated model presented in the paper. In nature, animals can employ a wide range of strategies and tactics, but most of all they are equipped with diverse weapons, such as horns, claws, fangs, and spines, that significantly influence their combat behaviour. As well as different levels of dangerous move they could employ it might vary in intensity according to environmental conditions, individual physical capabilities and prior experiences.

In addition, natural conflicts involve intricate signalling, a careful assessment of an opponent’s strength and often the presence of third parties either as allies or enemies. Despite the model reduces these complex behaviours to a limited set of strategies, its conclusions remain robust: even when allowing for a range of modifications, the Hawk strategy will consistently fail to emerge as an Evolutionarily Stable Strategy.

CONTINUATIONS

It is now licit to ask: how far can the conclusions of the last chapters really go? Maynard and Price analysed five different strategies, each named after a particular species. But in the end, these are just simplifications, how much truth can be extracted from them when considering a still indefinite number of species who possess different cognitive abilities?

The Earth is home to an incredibly diverse range of species, each fascinating in its own way. Yet, there’s one among them that stands out for the complexity and superiority of its brain: the human. Our brain has allowed us to diverge significantly from the animal world, so much so that we now ask to what extent can humans still be considered animals?

It’s a question that keeps leading to fascinating answers and new discoveries. In the final chapter of this thesis, I’ll explore how much of what it has been concluded so far can actually be applied to humans. The results might either reveal surprising similarities (proving how powerful Mother Nature is, even when working with limited brain capacity) or highlight a fundamental difference, showing how our ability to reason has led us toward a more efficient way of fighting, one that goes beyond what nature alone would have shaped.

HUMAN CONFLICTS: THE WAR OF DETERRENCE

PREFACE

To continue from the question left in the previous paragraph, I created a model with the aim of exploring whether humans are still children of their own mother, following natural instincts, or they have become something else, slaves to a technology destined to redesign the balance set by nature. In other words, the model tries to understand if the pattern observed in animal fights is still valid to explain human strategies, or if human equilibriums have been altered, far from their roots.

The object of study is the deterrence war: a way of holding back, of fighting without fighting that avoids destruction by holding it constantly on the edge of possibility. This is the limited way for humans to fight. It is far away from what nature alone has thought of, as human conflicts are influenced by macro-forces as politics, religion, power. Indeed, simplifications have been made, as well as realistic assumptions. The model does not rely on empirical data, but rather a theoretical framework built to make the problem manageable and isolate the mechanisms of the deterrence strategy.

Lastly, the result will be discussed with a broader reflection on today's global equilibriums. The aim is to rethink the way large-scale conflicts are perceived: not only as a threat, but also as a mean to maintain stability, where damage is not maximised, but rather minimised instead. Such perspective may offer a different understanding of modern deterrence, seeing it less as a source of fear and more as a tool for balance.

THE MODEL

Before diving into the model construction, it is useful to outline the key aspects of modern conflicts in order to justify the following choices. Nowadays, contemporary warfare is characterized by a strategic balance between deterrence and escalation, centred around the possession or non-possession of nuclear weapons. Countries may assume different positions on the use of force: from direct employment of highly destructive weapons, to mere possession as a form of deterrence or complete disarmament relying only on conventional tactics. These strategic differences affect deeply the stability of international relations and peace. By considering these elements, the model aims to study the real dilemma faced by nations between security and responsibility, and to explore under which conditions deterrence can be considered an Evolutionary Stable Strategy.

When building the model, I decided to opt for an approach that combines the front lectures of the Games & Strategies course, for completeness and modernity, and the model used by Maynard & Price in *"The Logic of Animal Conflicts"*, for similarity of the subject matter. My aim is to recreate such a model to assess whether the limited war in societal conflicts is an Evolutionary Stable Strategy as in the natural world. By analogy with the animal world, the deterrence war is the equivalent of the limited war in animals. Nuclear weapons are the most dangerous and lethal weapons ever created by men, thus when considering the use of them one should account also for all the negative consequences they will have, unlike animal weapons.

When defining a game based on a modern game theory approach, there are some key steps that must be followed:

1. *Define the players.*
   Nowadays, wars are fought between countries not men themselves. Thus, I considered two generical countries C_1 and C_2 who do not refer to any real-world case.
2. *Define the set of strategies Ω_1 and Ω_2.*
   Since the aim is to investigate whether the deterrence approach is an ESS, I shall compare it to all the alternative countries have today, to make the work complete and truthfulness. I identified three main strategies each country could adopt:
   a. $N =$ use of nuclear weapons (or, in general, extremely dangerous weapons) as a mean to solve conflicts.
   b. $D =$ detention of nuclear weapons for protection and defence, refraining from using them first and employing "normal" weapons otherwise.
   c. $U =$ disarmed of nuclear weapons, unable to reply to a nuclear attack, employing solely normal means.

   Thus, $\Omega_1 = \Omega_2$.
3. *Describing the payoffs assigned to each strategy.*
   It is not any easy job to assign payoff when simplifying a real-world case, as no exact number can be suggested. Therefore, I decided not to distribute any number, which is a common practice when just comparisons are enough to draw conclusions. It must be remarked the complexity of social warfare scenarios, where diplomacy, timing, fear and so on have an influence on the outcome. Indeed, we can imagine the use of nuclear weapons as only a part of a bigger equation, but even if ignoring the general form of it, it can be assessed whether deterrence increases, decrease or none a general country's payoff with respect to its alternatives. For the scope of the model, I chose four components that should be taken into account when determining a strategy's payoff:

a. $P =$ profit from a victory (i.e. territory and resources, net of losses).

b. $C =$ cost of receiving a nuclear attack.

c. $S =$ sanctions and alliances against the country who employed nuclear weapons.

d. $W =$ cost of using alternative and less dangerous weapons.

Note that they are all constructed to be positive quantities a priori.

4. *Drawing the payoff matrix.*

Before plotting the matrix, I decided to report the expected payoff of each strategy against the others for clarity purposes (which will then inserted in the matrix), recalling the approach used in *"Replication and Explanation of the Model"* in *"The Logic of Animal Conflict"*. Given the three strategies described above, nine different situations can verify:

a. $E_N[N] = \frac{1}{2}P - C - S$, since when two N fight each other, both employ nuclear weapons receiving C and S in response. The half is due to the fact that only one will win, with equal possibility in our simplified model.

b. $E_N[D] = \frac{1}{2}P - C - S$, equal to the previous case since when N attacks, D will reply with a nuclear attack too, behaving like two N fighting.

c. $E_N[U] = P - S$, as the unarmed country can't reply with a nuclear attack, leading the opponent to a guaranteed victory without incurring in the risk of receiving C.

d. $E_D[N] = \frac{1}{2}P - C - S$, analogous concept of $E_N[D]$.

e. $E_D[D] = \frac{1}{2}P - W$, where each country wins with probability a half, employing only normal weapons at a cost W, since no one will ever start probing first.

f. $E_D[U] = P - W$, since the country who adopts strategy D against U always wins due to the nuclear threat, even if adopting only nuclear weapons.

g. $E_U[N] = -C$, as U loses against N, incurring in the cost of receiving a nuclear weapon to which they can't counterattack in any way.

h. $E_U[D] = -W$, according to the same logic as in the previous cases.

i. $E_U[U] = \frac{1}{2}P - W$, the classic conflict without extremely dangerous moves, where each country wins with probability a half and face costs W.

Here it follows the corresponding matrix, where the comma separates the payoff of the two players (or countries):

$$\begin{array}{c} \\ N \\ D \\ U \end{array}\begin{array}{c}\begin{array}{ccc} N & D & U \end{array}\\ \begin{bmatrix} \frac{1}{2}P-C-S,\ \frac{1}{2}P-C-S & \frac{1}{2}P-C-S,\ \frac{1}{2}P-C-S & P-S,\ -C \\ \frac{1}{2}P-C-S,\ \frac{1}{2}P-C-S & \frac{1}{2}P-W,\ \frac{1}{2}P-W & P-W,\ -W \\ -C,\ P-S & -W,\ P-W & \frac{1}{2}P-W,\ \frac{1}{2}P-W \end{bmatrix}\end{array}$$

Now that the game has been defined, the next step is to study such game, finding its Nash Equilibria and its ESS. Since the aim of my attempt is to demonstrate if (D, D) is evolutionary stable, only pure strategies will be considered, disregarding the game in its mixed form.

Firstly, it must be noticed the symmetry of the matrix, where in Game Theory it is defined as the condition in which both players have the same set of strategies ($\Omega_1 = \Omega_2$) and they have a symmetric payoff ($E_{1,I}[J] = E_{2,J}[I]$). The utility of such symmetry will be revealed later in the text, but it is a good practice to notice such matrix properties a priori. Secondly, before starting the NE search, the existence of strictly dominated strategies should be checked. It is not a compulsory step, but it proves to simplify both the investigations on NE and ESS to a variable extent, according to the complexity of the matrix. In this case, for player 1, strategy U is strictly dominated by D since all its payoffs are strictly lower:

$\frac{1}{2}P - C - S > -C, \frac{1}{2}P - W > -W$ and $P - W > \frac{1}{2}P - W$.

And again, for player 2, strategy U is strictly dominated by strategy D:

> $\frac{1}{2}P - C - S > -C$ and $\frac{1}{2}P - W > -W$ (since the last row has just been eliminated form the game).

Therefore, our matrix game reduces to:

$$\begin{array}{c} \\ N \\ D \end{array}\begin{array}{c}\begin{array}{cc} N & D \end{array}\\ \begin{bmatrix} \frac{1}{2}P-C-S,\ \frac{1}{2}P-C-S & \frac{1}{2}P-C-S,\ \frac{1}{2}P-C-S \\ \frac{1}{2}P-C-S,\ \frac{1}{2}P-C-S & \frac{1}{2}P-W,\ \frac{1}{2}P-W \end{bmatrix}\end{array}$$

Once the game has such form, it is easier to find its Nash Equilibria, if they exist. Indeed, there are two NE: (N, N) and (D, D) <u>under the assumption that</u> $\frac{1}{2}P - C - S < \frac{1}{2}P - W$ and so $C + S > W$. If the assumption holds, when the game in is (N, N) no player has incentive to deviate since other strategies has equal expectation. When it is in (D, N) or (N, D), respectively C_2 or C_1, has incentive to deviate toward strategy D, where a highest payoff is expected.

The logic behind the assumption, is that a deterrence strategy can be a Nash Equilibrium and (maybe) an Evolutionary Stable Strategy only in the case where the damages suffered by a counterattack plus the sanctions received and alliances against the country are higher than the simple cost of using less dangerous weapons. Since nuclear attacks have disastrous consequences, the reality confirms the assumption. Indeed, even in the case of weak sanctions, the countereffects are so serious that the inequality can still be verified.

Finally, the last step of the analysis asks to verify which among the Nash Equilibria is evolutionary stable among time. As explained in "Preface on Game Theory", there exists a precise algorithm to establish whether a NE is also an ESS. The utility of the matrix symmetry can now be understood, since to exploit the algorithm, the NE must be a symmetric one.
Here it follows the algorithm, repeated both for (N, N) and (D, D) since they are symmetric NE (note how the process has been simplified by the elimination of the strictly dominated strategies).

(N, N):

1. Denoting $\sigma = N$, then $f(\sigma, \sigma) = f(N, N) = \frac{1}{2}P - C - S$.
2. Investigating how each pure strategy behaves with respect to σ:
   N: $\sigma(N) = 1$ since the pure strategy N is played with probability 1 under σ, so it is case 1;
   D: $\sigma(D) \neq 1$, it is not case 1.
   $f(D, \sigma) = f(D, N) = \frac{1}{2}P - C - S$ which is equal to $f(\sigma, \sigma)$, thus it is not case 2.
   $f(D, D) = \frac{1}{2}P - W > f(\sigma, D) = \frac{1}{2}P - C - S$, it is case 3b.
3. Since one of the pure strategies is case 3b, (N, N) is not an ESS.

(D, D):

1. $\sigma = D$, $f(\sigma, \sigma) = \frac{1}{2}P - W$.
2. N: $\sigma(N) \neq 1$, thus it is not case 1.
   $f(N, \sigma) = \frac{1}{2}P - C - S < f(\sigma, \sigma)$, it is case 2.
   D: $\sigma(D) = 1$, case 1.
3. Therefore, (D, D) is an ESS.

CONCLUSION

As shown by the game, the deterrence strategy proves to be evolutionarily stable over time. This lead to the conclusion that, in certain respects, human behaviour is more similar to that of animals than one might initially assume. Humans have naturally converged toward this equilibrium, consciously or not, recognizing that a limited war strategy is often the optimal way to manage conflict, as it minimizes unnecessary damage and preserves life. It is a striking result, highlighting the power of Mother Nature, who still models and shape the world. Einstein famously remarked that a mouse would never build a mousetrap, implicitly criticizing human folly; yet in reality, even a mouse can harm its own kind, but no animal would challenge an opponent they cannot possibly defeat. That must be folly. In this sense, the deterrence strategy reflects a deeply rooted, almost instinctive logic shared across species.

FINAL DISCUSSION

The analysis presented in this thesis leads to a somewhat unsettling but realistic reflection on the nature of human conflicts. While deterrence strategies often rise fear and some criticism, they may instead represent the approach that causes the least harm in an "imperfect" world. Unfortunately, the dream of a world ruled only by diplomacy is for now unfeasible. Deterrence strategies offer instead a way to prevent large-scale violence. Despite deterrence not being flawless nor a universal optimal solution, it faces the difficulty to overcome certain aspects of the human nature.

As much as we like to see ourselves as rational and cooperative, history suggests that conflict is not just a mistake or failure, but sometimes it is a reflection of deeper instincts. Beneath the surface of civilization, humans might show occasionally a tendency for aggression and competition, especially when survival or vital interests are at stake: the so-called love for the war. There is some truth in the idea that the humankind has an ambiguous relationship with war, they are attracted by its power of resolution while fearing the destruction it brings.

TODAY

To understand how these primordial forces play out today, it is enough to look at how states manage conflict and avoid escalation. The global system is shaped by rules, agreements, and balances of power that reflect the same logic seen in the model developed in this thesis. The behaviour of modern states shows how deterrence works in practice, confirming the model's conclusions about the balance between threat, cost, and restraint.

The ongoing rivalry between the United States and Russia is a clear example of such dynamics. Though the Cold War ended long ago, the logic of deterrence still shapes their relations. Both nations finance vast nuclear arsenals, managed by carefully designed systems to avoid accidents or unauthorized use. Coherently with the model built in the last section of this thesis, economic sanctions have been employed as a tool of pressure and signalling: from the sanctions imposed on Russia after the annexation of Crimea in 2014 (Council of the European Union, 2014) to the measures taken following the invasion of Ukraine in 2022 (U.S. Treasury, 2022). But as real cases reveal, even weak sanctions do not deny the validity of the model assumption ($C + S > W$), which should be better referred to as a general law. Indeed, the threat and damages from a counterattack are so high that makes the improbability very close to the impossibility of a nuclear use. As the model developed in this thesis shows, the combination of potential damages from a counterattack and the heavy costs imposed through international sanctions creates a powerful disincentive for the use of nuclear weapons. The anticipation of destruction, loss of human lives and international isolation is sufficient to keep nuclear powers locked in a delicate balance.

In this sense, today's geopolitical patterns confirm the conclusions of the model: it is precisely the awareness of the unbearable costs that pushes countries to avoid crossing the red line. At the same time, this observation invites a deeper reflection on the delicate balance we depend on. While deterrence has so far been effective in preventing the most extreme forms of conflict, it is not a permanent solution nor a guarantee of lasting peace. Yet it offers a working framework, which if carefully managed can strengthen stability and explore more sustainable forms of balance over time. Recognizing the tensions built into human nature does not mean bowing to them, rather it opens the way to gradually building a system where caution, restraint and cooperation can coexist, even in a world shaped by competition and risk.

A LESSON FROM DETERRENCE

This delicate balance between threat and restraint not only shapes international relations, but also recalls patterns long observed in the natural world. Just as many animal species rely on displays of strength and signals of warning to avoid deadly fights, human societies have developed complex strategies to manage conflict and preserve peace. To better understand these dynamics and the deeper lessons they hold for the humankind, I deemed helpful to report some extracts of thinkers who have explored deterrence before at different époques.

The economist and strategist Thomas Schelling, who was awarded the Nobel Prize in Economic Sciences in 2005, offers one of the most game-changing insights into deterrence. In The Strategy of Conflict (1960) he shows that peace is not achieved by removing danger, but by using it as a tool to shape behaviour. Schelling argues that the calculated use of threats, combined with a degree of unpredictability, can prevent opponents from making reckless moves. His lesson is both subtle and powerful: in a world where conflict cannot always be avoided, the real challenge is to learn how to manage risk, turning potential threats into instruments for stability. This idea finds an often underestimated parallel in nature that has always been under the eyes on many, indeed many animals turn danger to their advantage too: a pufferfish inflates to appear larger when threatened, some snakes mimic the appearance of venomous species or some insects even have a plant-like appearance. Deterrence in this sense teaches that danger itself can be transformed into a safeguard not by eliminating it, but by harnessing it wisely.

The philosopher Thomas Hobbes in his classic work Leviathan (1651) offers a perspective that helps explain why deterrence can work. Hobbes argued that humans, by nature, live in a state of fear and mistrust, where the absence of a strong authority leads to a constant conflict (in latin "homo homini lupus" from Plauto's work Asinaria: "man is a wolf to man"). According to him, what keeps people from attacking each other is not trust or morality, but the fear of punishment and defeat. The lesson Hobbes offers is clear and relevant: peace is often preserved not through goodwill, but through the fear of consequences. This reminds patterns found in nature, where many animals avoid dangerous fights not out of empathy, but because the cost of injury or exhaustion is too high. Wolves, for instance, engage in ritualized displays rather than deadly fights for dominance and many predators abandon a chase when the risk of injury outweighs the potential reward. Hobbes's insight reminds us that fear, while uncomfortable, can play a constructive role in limiting violence and that understanding these instincts allows us to build more realistic and stable form of peace.

Taken together, the lessons of Schelling and Hobbes remind that the roots of deterrence lies not only in political systems, but in human nature itself. Both thinkers show that peace is rarely the product of perfect trust or moral progress, but often the result of managing risk, fear and competition with care. Their reflections is an invite to look forward, where understanding the forces at play is the first step toward reducing tension and exploring new ways to prevent conflict, without ignoring the realities of the world.

Perhaps the greatest challenge is not only to recognize these patterns, but to imagine how they might evolve or how the same instincts that once drove survival through confrontation could be redirected toward cooperation, restraint and security. This calls for a kind of creativity and courage: the ability to work with our nature without being trapped by it, to transform the logic of conflict into opportunities for balance and coexistence.

"By understanding the instincts we share with the natural world, we may yet find the wisdom to rise above them."

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