Strategic Deterrence: A Game-Theoretic Analysis of Nuclear Weapon Usage

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Abstract

This research paper provides an analysis of nuclear weapon usage in the present-day world through the lens of game theory. Despite the existence of nuclear weapons as the most formidable and threatening form of warfare, this paper explores the reasons behind the non-usage of nuclear weapons despite multiple armed conflicts since its only recorded use in human history in 1945. Through an examination of historical events, such as the Cuban Missile Crisis, this paper illustrates how nuclear cooperation has been established to prevent damaging nuclear conflict. Furthermore, this paper generalizes this analysis to the present-day global landscape, highlighting why nuclear weapons exist primarily as deterrents that act as signals rather than active tools of warfare and destruction. This study is grounded in mathematical game-theoretic concepts, although non-mathematical and intuitive explanations of such concepts also exist to provide the reader with a holistic understanding of basic game theory.

Introduction to Nuclear Weapons

Dubbed “the most dangerous weapons on Earth,” nuclear weapons have the scary potential to kill billions and significantly jeopardize the lives of future humans. Yet, despite their frightening potential, nuclear weapons exist mainly as a threat of warfare that bolsters both the military strength and credibility of a nuclear-armed nation. Spurred on by numerous developments in atomic theory in the scientific world, the development of nuclear weapons rapidly accelerated throughout the mid-20th century due to World War II. The first nation to achieve a breakthrough was the United States: on July 16, 1945, the world’s first atomic bomb detonated in the desert of New Mexico, marking the success of America’s initiative to create a nuclear weapon and forever changing the course of humanity.

It was at this time that J. Robert Oppenheimer, widely regarded as the father of the atomic bomb, famously uttered the words, “Now I am become death, the destroyer of worlds.” A mere three weeks later, American President Harry Truman authorized the use of atomic bombs to be dropped on the Japanese cities of Hiroshima and Nagasaki. It is estimated that around 200,000 civilians were killed as a result of the bombings; six days later, Japan unconditionally surrendered to end World War II. Ultimately, the discovery of atomic bombs not only brought World War II to an abrupt and fiery end but also ushered humanity into a new era of warfare that forever changed the nature of global conflict. In the years to follow, the quest for global nuclear domination led to the Cold War between the United States and the former Soviet Union, marked by an arms race between the two nations.

Today, nine nations around the world have either shown or are believed to have access to nuclear weapons: the United States, Russia, China, France, the United Kingdom, India, Pakistan, North Korea, and Israel. Israel is widely believed to have nuclear weapons, but maintains a policy of strategic opacity. Several other countries formerly possessed nuclear weapons but have since given them up, including South Africa (who voluntarily relinquished their nuclear arsenal) and the former Soviet states of Kazakhstan, Belarus, and Ukraine (whose nuclear weapons were moved to Russia). Of these countries with nuclear capabilities, the United States and Russia account for a whopping 90% of the world's nuclear weapons. However, despite the wide existence of nuclear weapons, the last time they were used to cause human casualties intentionally was in fact during World War II, almost eight decades ago. Furthermore, the global nuclear stockpile has decreased from 60,000 during the peak of the Cold War to only 13,000 in the present day. This begs the question of exactly why nuclear weapon usage and stockpile quantity have significantly decreased despite it being the most powerful weapon known to mankind. However, there is an intuitive and sophisticated framework that helps to explain the status quo of present-day nuclear weapon usage: game theory.

Introduction to Game Theory

Largely credited to the works of mathematician John von Neumann and economist Oskar Morgenstern in the 1940s, game theory is the study of mathematical models that analyze strategic interactions between individuals or entities. Combining the fields of mathematics, economics, philosophy, and psychology, game theory can be applied in countless fields as a theoretical framework that helps explain how and why individuals make rational choices in many different situations. Game theory plays a vital role in our world; in fact, its relevance can be shown by twelve economists being awarded the Nobel Prize in Economic Sciences over the past fifty years for their contributions to game theory. In today's world, experts in the fields of economics, business, politics, psychology, science, and many more utilize game theory as a framework to aid in strategic decision-making. By understanding how individuals and entities can act rationally to best meet their own goals, society can both better realize optimal outcomes and predict future events with greater accuracy.

While much of simple game theory is quite intuitive, a salient part of game theory is the mathematics that formalizes such game-theoretic concepts; these mathematical models are crucial in building the backbone of the theory itself. In the next section, the simple yet fundamental concepts of game theory will be presented in both an intuitive and mathematical way. While there exist many more complex aspects of game theory, knowledge of these fundamental concepts is crucial in understanding how game theory can be applied to the real world.

Fundamental Concepts of Game Theory

As a general reminder, game theory is the study of repeated interactions between individuals or entities. In game theory, a game refers to a specific scenario where any number of players aim to make strategic decisions in their interaction with others. A player can be an individual, a group, a corporation, a nation, or any association that can be classified as a singular player within the game. When a player makes a decision or a choice, they aim to do one that is most desirable to them. The way to quantify this is to define this numerically as their utility, which is any real number that measures the satisfaction a player would derive from taking any specific action. The utility can be any number, either positive, negative, or zero, and the greater the number is, the higher the satisfaction the player would derive. Mathematically, the utility gained from a player i of action a is represented by $u_i(a)$. Utility functions are one of the most important concepts within game theory.

Normal Form Games

A *normal form* game is the most standard representation of a game in game theory. A game is said to be in normal form if:

- The set of finite players is $N = \{1, ..., n\}$
- Each player i has a set of strategies S_i available for $i \in N$. The combination of all sets of strategies is $S = S_1 \times \cdots \times S_n = \prod_{i=1}^{n} S_i$
- Each player i has a utility function $u_i : S \rightarrow R$ for $i \in N$. Simply, $u_i(s)$ is the utility derived by player i from strategy s, where $s \in S$ and $u_i(s) \in R$.

To explain in non-mathematical terms, the first condition establishes the existence of a finite number of players within the game, the second condition establishes the existence of a set of strategies for each player within the game, and the third condition assigns a certain utility value that each player receives based on their actions and the actions of the other players. Additionally, a relevant yet non-crucial distinction to make is that the set of strategies S_i for $i \in N$ are pure strategies, meaning that a player chooses a single action and sticks with it (as opposed to mixed strategies, where a player probabilistically chooses their action). The set of strategies S_i for $i \in N$ can also be either finite or infinite.

In simpler games where only two players exist and their sets of strategies are limited to a smaller number of actions, their utility functions can be represented in a payoff matrix, which provides a visualization of a normal form game. For example, consider the following table:

Example Payoff Matrix

	Player 2: Action X	Player 2: Action Y
Player 1: Action A	(3, 1)	(2, 0)
Player 1: Action B	(0, 2)	(-2, -2)

Here, Player 1 has the choice to take actions A or B, and Player 2 has the choice to take actions X or Y. The four payoff values represent the utility derived by each player based on the actions taken by Players 1 and 2. For example, if Player 1 takes action A and Player 2 takes action X, the utility payoff shown in the appropriate box is (3, 1). This means that from these actions, Player 1 would have a utility value of +3 and Player 2 would have a utility value of +1. The payoff matrix is a simple yet effective way to visualize a normal form game and will be used extensively during the analysis later on.

Nash Equilibrium

Before exploring concepts of equilibrium, it is important to define notations of each player's strategies. The following mathematical definitions are corollaries of the standards of a normal form game established above:

- $s = (s_1, ..., s_n) = (s_i, s_{-i}) \in S$ for $i \in N$
- $s_{-i} = (s_1, ..., s_{i-1}, s_{i+1}, ..., s_n)$ for $i \in N$
- $S_{-i} = \prod_{j=1}^{n} S_j$ where $j \neq i$
- $S_i \times S_{-i} = S$

In non-mathematical terms, there exists a specific strategy s_i that is unique to a player $i \in N$, and s_{-i} refers to the set of strategies by all other players *except* player i. Additionally, the strategy set of player i, S_i, taken together with the strategy set of all the other players except player i, S_{-i}, combine to make up the combination of *all* sets of strategies, S.

Another notable concept in game theory is the *Nash Equilibrium*, named after the American mathematician John Nash, who was awarded a Nobel Prize in Economics in 1994. A Nash Equilibrium describes a situation within a game where no singular player could achieve any gain by changing their own strategy, assuming the strategy of the other players is unchanged; in effect, the game has reached a point of equilibrium. For a player $i \in N$, a specific strategy $s_i \in S_i$ is a *best response* to a profile of strategies $s_{-i} \in S_{-i}$ if:

- $u_i(s_{i,} s_{-i,}) \geq u_i(s'_{i,} s_{-i})$

for all $s'_i \in S_i$. A player's best response is a strategy that produces the highest utility outcome for the player, assuming the other players' strategies are constant and don't change. If the best response of a player i to other players' profile of strategies s_{-i} is a unique best response (i.e. if the utility function on the left side of the inequality is strictly greater than the utility function on the right side), the specific strategy s_i is a *strict best response*. The symbol ′ in s'_i is known as the "prime" of the set s_i, which notationally denotes the complement of set s_i. The complement of a set is everything that is not in the set but is within a larger set. For example, if there exists a set (2, 4, 6, 8), and a set *A* is defined to be (2, 4), then *A′* is (6, 8) as those are the terms that exist within the larger set but aren't in set *A*. *A*' (pronounced "*A* prime") is the complement of set *A*.

Now, a set of strategies $s^* = (s^*_1, ..., s^*_n) \in S$ is a *pure strategy Nash Equilibrium* if:

- $u_i(s^*) = u_i(s^*_{i,} s^*_{-i,}) \geq u_i(s_{i,} s^*_{-i})$

for all $s_i \in S_i$ and $i \in N$. In non-mathematical terms, s^*_i refers to the equilibrium strategy of a player i and s_i denotes any possible strategy player i can choose (not necessarily the equilibrium strategy). Additionally, for a player i, their set of strategies s^*_i is a best reply to the strategies of all the other players, s^*_{-i}. If the utility derived by a player i from a set of strategies s^* is a unique best response (i.e. if the utility function on the left side of the inequality is strictly greater than the utility function on the right side), there exists a *strict Nash Equilibrium*. In a strict Nash Equilibrium, no player can increase their payoff by unilaterally changing their strategy. While these two aforementioned explanations seem incredibly similar, the only difference is that the first refers to a specific strategy, s_i, whereas the second refers to an entire set of strategies, s^*_i. Intuitively, if every player $i \in N$ has played the strategy that gives them the highest utility payout, a Nash Equilibrium would be formed as each player would have no incentive to change their strategy as their highest possible utility would've been achieved. A Nash Equilibrium has the property that no player would regret having played the action that they played in the game, assuming the strategy of the other players remains unchanged.

Now, following the mathematical definitions described above, let's present a couple of examples of finding a Nash Equilibrium within a 2x2 payoff matrix below. The first example is a coordination game called the Stag Hunt Game, coined by the philosopher Jean-Jacques Rousseau. In this game, the two players (two hunters) A and B each have the option to either hunt for a stag (strategy labeled S) or a hare (strategy labeled H):

Stag Hunt Game

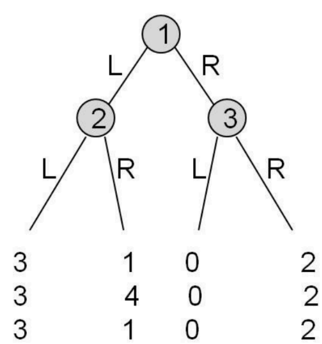
	Player B: S	Player B: H
Player A: S	(5, 5)	(0, 3)
Player A: H	(3, 0)	(4, 4)

To successfully hunt a stag, the efforts of both hunters are required, but both hunters taking the action of hunting for a stag together result in the best mutual outcome. However, the two hunters are unaware of the other's strategy as they are physically separated without any communication. As a result, a more risk-averse hunter might opt to hunt for a hare as they are easier to catch, and it guarantees a minimum payout of +3 while the minimum payout of choosing a stag is 0, as a stag is too large to be hunted alone. In this specific game, there exist two pure strategy Nash Equilibria: the choices of (S, S), and (H, H). To find these Nash Equilibria, we must analyze each player's best response given the other player's action. If player A chooses S, player B will also choose S as the payoff of choosing S (+5) is greater than choosing H (+3). If player B chooses S, player A will likewise also choose S due to the higher payout. In the case players A and B have chosen (S, S), neither will have the incentive to change their strategy, assuming the other player's strategy remains constant, resulting in one Nash Equilibrium. Similarly, if player A chooses H, player B will also choose H as the payoff of choosing H in this situation (+4) is greater than choosing S (+0). If player B chooses H, player A will also choose H due to the higher payout. In the case players A and B have chosen (H, H), neither player will have the incentive to change their strategy (assuming the other player's strategy remains constant), resulting in the second Nash Equilibrium. While there are many games with only one pure strategy Nash Equilibrium, the case of the Stag Hunt Game provides an example of a game that has more than one pure strategy Nash Equilibrium.

However, it is possible that a game might not have any pure strategy Nash Equilibria: an example is the Matching Pennies Game, where two players simultaneously place a coin on a table and if the results match (i.e. Heads and Heads or Tails and Tails), player A wins, and if the results don't match, player B wins. In the Matching Pennies game, there is no pure strategy Nash Equilibrium as each player's best response continuously changes with the other player's choice.

Backward Induction & Extensive Form Games

Previously, we encountered normal form games where each player $i \in N$ selected a strategy with beliefs about the other players' strategies, but not full knowledge (as players move simultaneously). In contrast to normal form games, *extensive form* games describe situations where players make actions sequentially, having knowledge of all previous actions that have been performed prior to their move. Extensive form games allow one to understand strategies in response to the strategies of others, as the game changes from being played simultaneously to sequentially. For simplicity, this paper only discusses finite extensive form games of perfect information, where players take actions sequentially in a specific order, every player is knowledgeable about all previous information, and every player only moves a finite number of times. The simplest and most effective way to visualize an extensive form game is through a game tree, where nodes of the tree represent a specific stage of the game. The game starts from a node called the initial or root node, and branches that connect to other nodes represent the actions taken by a player. Nodes that don't traverse to another node are called terminal nodes, which end the game. At the end of each terminal node, utility values are listed for each player $i \in N$. Every other node, called a non-terminal node, represents various stages within the game where a player can take a specific action. The specific player that has the choice to take an action is specified by the non-terminal nodes, and their action is represented by branches. For example, consider the following game tree that gives a visual representation of an extensive form game:



In the above figure, the game starts with player 1 having the choice to either choose action L (left) or R (right). If player 1 chooses action L, player 2 can then choose either action L or R; however, if player 1 chooses action R, player 3 has the choice to choose action L or R. At the end of every terminal node, a utility payoff table is shown with the top value representing player 1's utility, the middle value representing player 2's utility, and the bottom value representing player 3's utility. Simply, the players' actions create a path through the tree and dictate each player's utility outcomes. For example, if player 1 took action L and player 2 also took action L, all three players would end with a utility of +3, as specified in the utility payoff table.

Interestingly, a Nash Equilibrium can be found in this game through means of *backward induction*, or traversing backward through the tree and making rational assumptions about what each player would do assuming their intention is to maximize their own personal utility. Consider the choice of player 2 if player 1 chooses the action L. Player 2 will then choose the action R, as the payout of +4 > +3. Now, if player 1 chooses the action R, player 3 will choose action R as their payout of +2 > 0. Player 1 will foresee these choices and decide that they would rather get a payout of +2 (if they choose action R) over +1 (if they choose action L). As a result, player 1 would choose action R, player 3 would choose action R, and each player would end up with a utility value of +2 at the end of the game. This outcome represents a pure strategy Nash Equilibrium. More generally, every finite extensive form game of perfect information has a pure strategy Nash Equilibrium.

An important note to make is that moving first in an extensive form game can be either advantageous or disadvantageous. In the example discussed above, player 1 has the advantage of rationally predicting what moves players 2 and 3 would make based on player 1's move. However, this isn't always the case; sometimes, the players that move after benefit from knowing which strategy the first player has taken. For example, consider the aforementioned Matching Pennies game; in that example, the player moving last would always have the significant advantage of knowing all previous actions taken by the other player.

In extensive form games when utilizing backward induction, it's only necessary (and simpler) to just understand the intuition behind the analysis rather than the mathematics. However, as I did with normal form games, I now provide a simple overview of the mathematics behind extensive form games. A finite extensive form game of perfect information consists of the following:

- A finite set of players $N = \{1, ..., n\}$
- A finite set of nodes $X = \{x_1, ..., x_n\}$ that form the game tree
- A finite set of terminal nodes $Z = \{z_1, ..., z_n\}$ where $Z \subset X$
- At each non-terminal node $x \notin Z$, there exists a player $i(x)$ for $i \in N$, a set of possible actions $A(x)$, and a successor node $n(x,\ a)$ resulting from any action $a \in A$
- A utility function $u_i : Z \rightarrow R$ for $i \in N$. Simply, $u_i(z)$ is the utility gained by player i if a terminal node $z \in Z$ is reached.

Now, the informal explanation of the existence of a pure strategy Nash Equilibrium in every finite extensive form game of perfect information goes as follows, assuming the aforementioned mathematical definitions. To start, we can create a set S that contains the K stages of the game such that $S = \{1, ..., K\}$. Consider all the nodes x in stage K; it is known that the player i who moves will make a move that maximizes their utility; let's call this specific move m_K. By backward induction, now move to stage $K - 1$. Every other player will assume that the player i who moves at stage K will make the specific move m_K. With this knowledge in mind, the player moving at stage $K - 1$ will look for the move that maximizes their utility (accounting for move m_K as well). Once this choice is found, we move to stage $K - 2$, and this process will continue until stage 1 is reached. As a result, due to the fact that every player $i \in N$ has full and perfect knowledge about every stage of the game, there exists a pure strategy Nash Equilibrium in every finite extensive form game of perfect information.

In contrast to normal form games where each player moves only once and actions are taken simultaneously, extensive form games account for the sequential timing of strategic decisions where players can also move more than once. While both of these forms of games have relevant applications, it should be noted that any finite extensive form game can be represented in the normal form, allowing for both forms to be used in various game scenarios.

Things to Consider & Important Notes

To conclude this section, let's look at some important concepts to remember when dealing with game-theoretic concepts. The following are all crucial concepts that should be defined when dealing with game theory: the players, all the actions available to each player, the timing of the interactions (i.e. simultaneous or sequential moves), the order of the players' actions, the information available to players at every stage of a game, and the utility payoffs for each player based on the actions played. The utility payoff function of each player should take into account both the costs and benefits of every potential outcome.

Additionally, one of the most essential and basic assumptions that much of game theory operates under is that players within a game are rational and self-interested (i.e. they take actions that are optimal for them). Of course, this isn't always the case in reality due to the existence of inherent human irrationality, but having players within a game act rationally helps to provide a clearer understanding of many scenarios. Additionally, this paper is based upon the principles of *noncooperative game theory*, where every player acts self-interested without the existence of any binding agreements with each other, as opposed to cooperative game theory. This is a crucial distinction to make, so it should be noted that every player acts in their own best interest within the examples discussed in this paper.

Finally, it should be noted that the game-theoretic concepts covered so far in this paper are not all that game theory has to offer. There are countless more topics in game theory, but many of these topics are significantly more advanced and, more generally, are outside the scope of this paper.

Analysis of Present-Day Nuclear Weapon Usage

This section provides a comprehensive game-theoretic analysis of present-day nuclear weapon usage and predictions for future prospects. As a reminder, today, nine nations around the world either have or are believed to have access to nuclear weapons: the United States, Russia, China, France, the United Kingdom, India, Pakistan, North Korea, and Israel (with a modicum of opacity). Additionally, Iran has a controversial nuclear program, claiming it is for peaceful purposes while others suspect otherwise; Saudi Arabia has expressed interest in nuclear technology if Iran develops nuclear weapons; Turkey is described by some expert analysts to be considering nuclear weapons given regional tensions; and Japan has the technical capabilities but has chosen not to develop nuclear weapons due to its pacifist constitution.

In this game-theoretic analysis, however, we only consider the interactions between two countries, Country A and Country B. While in reality there could exist interactions between several countries in a nuclear context, reducing the interaction to only two nations helps simplify the game-theoretic analysis and provides a clearer, more intuitive understanding of the existing affairs of nuclear weapon usage. To start, we define the specific parts of this game in normal form, in accordance with the mathematical definitions of a normal form game shown above:

- The set of players is finite. There exist *two* players: Country A and Country B
- Each player in the game has strategies: *Use Nukes* and *Don't Use Nukes*
- Each player in the game has a specific utility value for all of the game's outcomes

Since this is a relatively simple game with only two players and two strategies available for each player, their utility functions resulting from the potential outcomes of the game can be visualized in a two-by-two payoff matrix, shown below:

Payoff Matrix for Present-Day Nuclear Weapon Usage

	Country B: Use Nukes	Country B: Don't Use Nukes
Country A: Use Nukes	(-10, -10)	(3, -6)
Country A: Don't Use Nukes	(-6, 3)	(4, 4)

Looking at this table, it becomes apparent that both nations using nukes is the mutually worst outcome, as they both earn a utility value of -10. This intuitively makes sense, as both nations using nuclear weapons would be detrimental to both parties, and could quickly spiral into a continuing conflict with potentially severe damage. If Country A uses nukes and Country B doesn't, then Country B suffers the damage of the nukes used on them, hence earning a utility value of -6. This utility value is greater than that of -10, as presumably the conflict would be resolved at that moment without the immediate potential for more nuclear damage. Country A would earn a utility value of +3, as they would likely have won any conflict or dispute without suffering any damages from nuclear weapons. However, the reason this utility value isn't higher is they could potentially face repercussions from other nations or organizations due to their actions and could be made a pariah on the international stage. The opposite event occurring (Country A not using nukes and Country B using nukes) would flip the utility values: Country A would earn a utility of -6 and Country B would earn a utility of +3. If both nations refrain from using nuclear weapons, they each earn a utility value of +4. While a conflict likely would not have been resolved without diplomatic intervention, neither nation would have suffered the significantly immense damages that would result from the usage of nuclear weapons. Logically, nuclear non-usage is the best outcome for both nations.

As a result, from the explanation given above, the outcome where both nations choose the option (*Don't Use Nukes*, *Don't Use Nukes)* is a pure strategy Nash Equilibrium. For a further explanation, consider the following, with all utility values mentioned below coming from the above payoff matrix. As a reminder, a pure strategy Nash Equilibrium is a situation where no singular player can unilaterally improve its utility (i.e. achieve a gain by changing their own strategy, assuming the strategy of the other player(s) is unchanged). From Country A's perspective, if Country B chooses the option of not using nukes, Country A will also choose that option. From Country B's perspective, if Country A chooses the option of not using nukes, Country B will also choose that option. In the case that both nations choose not to use nukes, neither player will have the incentive to change their strategy as they cannot receive a higher payout. As a result, since neither nation can unilaterally improve its utility, the outcome (*Don't Use Nukes, Don't Use Nukes*) represents a pure strategy Nash Equilibrium within the game. Mathematically, this outcome satisfies the definition of a pure strategy Nash Equilibrium as well.

It should also be noted the action *Don't Use Nukes* is a *dominant strategy* for both Country A and Country B in this game. A dominant strategy in game theory is a strategy that produces a higher utility than any other strategy, irrespective of the strategies played by the other player(s) in the game. When a dominant strategy holds, a player doesn't need to make predictions about moves from the other players; they just need to play the strategy that provides them the highest utility. When dominant strategies exist, the game-theoretic analysis of any event becomes simpler. However, it should be noted that in many games, dominant strategies do not always exist.

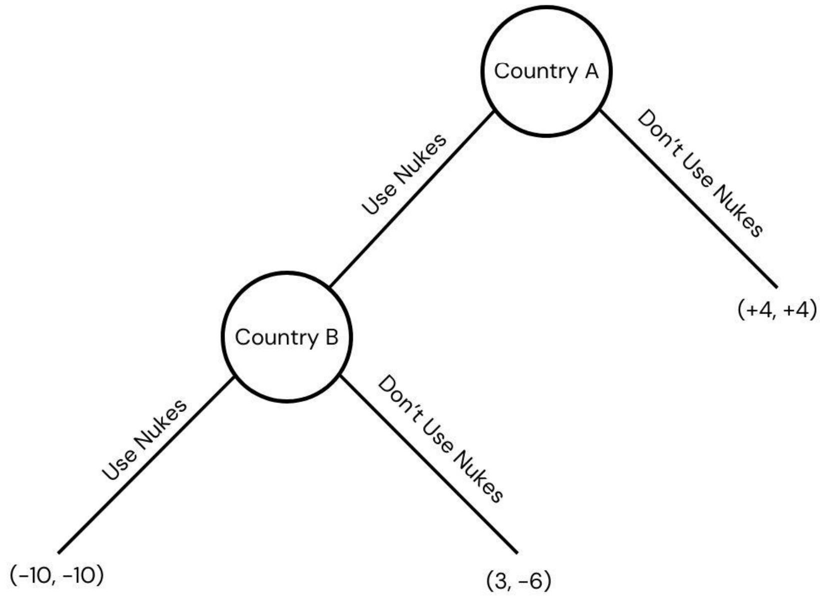
Extensive-Form Game Application

The previous section provided a game-theoretic analysis of present-day nuclear weapon usage in the normal form, meaning that both players within the game moved simultaneously. However, this game can also be modeled in extensive form, where players move sequentially. This adds another important concept to the game: time. In reality, strategies played by a player don't always occur immediately; likewise, in this case, a nuclear weapon isn't going to instantaneously reach its target once launched. Additionally, many developed nations have sophisticated defense systems that can detect the presence of any weapons launched. For example, it takes 26 minutes and 40 seconds for a nuclear weapon launched by Russia to reach the East Coast of the United States. In that time, the United States could feasibly detect the presence of a nuclear warhead barreling towards them, and have an adequate amount of time to mount a response. In this case, the United States would make a move *after* Russia, meaning this game can be modeled as an extensive form game.

As a reminder, an extensive form game allows one to understand strategies in response to the strategies of others, as the game is played sequentially. In this case, this game is a finite extensive form game of perfect information, meaning every player is knowledgeable about all previous information and moves only a finite number of times. Below, the specific parts of this game in extensive form are defined:

- The set of players is finite. There exists *two* players: Country A and Country B
- There exists a finite set of nodes
- Each player in the game has a specific utility function at each terminal node

Now, consider the following game tree that provides a visualization of this game in the extensive form between Country A and Country B:



The utility values shown in this game in extensive form are the same as those shown in the normal form for consistency within this paper. Here, Country B reacts to Country A only if Country A chooses the strategy *Use Nukes*. We can apply backward induction to this game tree to find the Nash Equilibrium. Consider the choice of Country B if Country A uses nukes. Country B will opt not to use nukes, as the utility of -6 is greater than -10. In this case, Country A will receive a utility value of +3. However, Country A also has the option not to use nukes, in which case they will receive a utility value of +4. As a result, Country A will opt to use the strategy of *Don't Use Nukes*, which is an equilibrium point. This is also Country B's best outcome as it provides its highest utility. The same logic applies when Country A reacts to Country B's actions (i.e. when Country A is switched with Country B in the above game tree).

In this case, modeling the game in extensive form helps account for the sequential timing of strategic decisions. However, it is helpful to visualize the games in both their normal form and extensive form. Throughout both of these forms of games, we have concluded that the best outcome for both Country A and Country B is for both of them to select the action *Don't Use Nukes*. This game-theoretic model helps support and explain the non-usage of nuclear weapons in the present-day world, despite their existence as the most formidable tool of warfare.

Implications for Present-Day Nuclear Strategy

Now, we explore how the above game-theoretic analysis compares to the actual present-day nuclear strategy of the countries with nuclear weapons. While our current world is riddled with conflicts, there isn't any evidence of nuclear weapons being used. All available data supports this claim in many different ways: for example, the present-day global nuclear stockpile contains around 13,000 weapons, a significant decrease from the 60,000 weapons during the peak of the Cold War. Additionally, many nations that were suspected of developing nuclear weapons have since abandoned such efforts. In the 1970s, more than a dozen nations were pursuing nuclear weapons, but since then, almost all of them have stopped their development efforts. Furthermore, publicly documented nuclear weapon tests have essentially ceased. In 1962, there were 178 recorded nuclear tests; today, there are almost zero. The last time nuclear weapons were used with the deliberate intent of causing human casualties was during World War II. The last time nuclear weapons were publicly aimed at another nation with a real threat of destruction was over sixty years ago, during the Cuban Missile Crisis.

Since then, nuclear weapons have primarily existed as a deterrent to conflict by being a show of credibility and strength. In economics, the term “signaling” refers to one party conveying some sort of information about itself to another party. In this context, nuclear weapons represent the perfect “signal”; they are a show of strength to other countries. Additionally, nations know that any nuclear outcome could represent an existential threat to humanity and are aware of the threat of mutually assured destruction (MAD). Mutually assured destruction, a principle of deterrence, refers to the idea that a nuclear attack by any one superpower would be met with a nuclear counterattack by another superpower, resulting in complete annihilation for both parties.

As a result, many countries around the world have aimed to reduce the collective threat that nuclear weapons pose through international agreements. For example, 191 countries have signed the Nuclear Non-Proliferation Treaty (NPT) which aims to prevent the spread of nuclear weapons and weapons technology. Additionally, 177 countries have signed the Comprehensive Test Ban Treaty (CTBT), which prohibits any nuclear weapon explosion anywhere in the world. More recently, 70 countries have signed the Treaty on the Prohibition of Nuclear Weapons (TPNW), which bans the use, possession, testing, and transfer of nuclear weapons under international law. While these treaties vary in degrees of prohibition and enforceability, the apparent underlying point is that the vast majority of countries in the world have legally agreed to reduce the threat of nuclear weapon destruction through binding agreements.

Implications for Future Nuclear Strategy

In the immediate future, nuclear weapon usage isn’t likely to significantly change from the status quo right now. While there are sure to be technological advancements in many different fields, the existential threat posed by nuclear weapons isn’t going to disappear, and countries around the world will remain aware of their threats. In fact, the last time our world came anywhere close to nuclear destruction was in October 1962 during the Cuban Missile Crisis.

The Cuban Missile Crisis refers to the confrontation between the United States and the Soviet Union during the Cold War that put the world on the brink of nuclear war. Following the failed American Bay of Pigs Invasion, the Soviet Union and Cuba reached an agreement to put Soviet nuclear missiles in Cuba to deter any future American invasion attempt. After an American U-2 spy plane photographed the nuclear missiles being built dangerously close to American soil, President Kennedy ordered a naval quarantine around the island of Cuba and demanded the removal of the Soviet nuclear weapons. Recognizing the dangerous possibility of a devastating nuclear war, Soviet leader Nikita Khrushchev agreed to remove the nuclear weapons from Cuba given that the United States would pledge not to invade Cuba, and in a separate deal not publicly revealed, remove their own weapons from Turkey. On October 28, Khrushchev publicly announced that the Soviet missiles would be removed from Cuba, and on November 20, 1962, the United States ended its naval blockade. In April 1963, the United States removed its nuclear missiles from Turkey.

Similar to the game-theoretic analysis of today's nuclear weapon usage, both the United States and the Soviet Union were faced with the same dilemma. In the end, both nations agreed to not use nuclear weapons and de-escalate the situation, resulting in the game-theoretic Nash Equilibrium (*Don't Use Nukes*, *Don't Use Nukes)*. Following the Cuban Missile Crisis, both nations took steps to improve their relations: a "Hotline" was established to improve communications and both nations signed the Limited Nuclear Test Ban Treaty in July 1963.

In June 1963, President Kennedy explained why both nations decided to de-escalate: "Our most basic common link is that we all inhabit this small planet. We all breathe the same air. We all cherish our children's future. And we are all mortal." In the end, the same framework and conclusions derived from today's analysis of nuclear weapon usage can be found in the Cuban Missile Crisis over sixty years ago. As a result, as long as the leaders and governments of our world remain rational, it can be safe to say that the results seen both in the past and the present will most likely remain the same in the near future.

Conclusion

Ultimately, game theory is a helpful framework that helps explain how and why various players make choices in any given situation. One of the many applications of game theory is analyzing the usage of nuclear weapons in the present-day world. Despite their existence as the most formidable tool of warfare, nuclear weapons have not been used with resulting human casualties in almost eight decades. Through the game-theoretic analysis extensively discussed in this paper, it has been illustrated how and why mutual cooperation has been maintained to prevent nuclear conflict and why nuclear arsenals are maintained more as deterrents and symbols of strength rather than active tools of war.

It is essential to recognize how the players or key factors in this game can change, which include countries that have nuclear weapons, countries that may later have nuclear weapons, international organizations, and new or expiring treaties. Furthermore, one of the most critical yet fair assumptions that game theory tends to act under is that the players in the game are rational. While this is always the case in theory and tends to be the case in reality, it's important to remember that not all players, especially humans, always act rationally. Overall, there will always be certain limitations when applying a theoretical framework to a situation in reality. However, game theory remains incredibly relevant by guiding players towards the most effective and rational strategies in any complex environment, and in this context, helps to analyze and prove the non-usage of nuclear weapons in the present-day world.

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