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A SIMULATION MODEL OF SANCTIONS AND  
NEGOTIATIONS: THE EXAMPLE OF THE IRAN  
NUCLEAR DISPUTE

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# Abstract

International conflicts are dynamic processes that develop over time. However, research on sanctions and negotiations has tended to neglect the dynamic nature of conflicts. Quantitative studies in these areas have primarily relied on static models. Therefore, they have not been able to provide adequate insights into the dynamic interactions between the involved actors and have not considered the dynamic contexts in which conflicts develop.

This dissertation expands existing literature by combining the two fields of economic sanction and negotiation research and further accounts for the dynamic nature of conflicts. Towards this end, a dynamic, agent-oriented simulation model is introduced and discussed with respect to an in-depth case analysis of the Iran nuclear dispute.

The results show that sanctions have the potential to influence conflict dynamics. Various factors of the sanction mechanism can thereby contribute to the escalation of a conflict. Furthermore, findings demonstrate that such an escalation can make a settlement more attractive and can lead to the acceptance of a negotiation solution, which was not acceptable prior to escalation. However, the results also show that such an agreement can be significantly more expensive and inferior to earlier negotiation solutions which had previously been disapproved by the conflict parties.

The findings of this dissertation increase the understanding about the effects of sanctions and the emergence of a negotiated agreement from a conflict situation. From a practical perspective, the results further highlight the importance of finding mechanisms to overcome costly escalation and promote timely negotiated agreements.





# Zusammenfassung

Internationale Konflikte sind dynamische Prozesse, die sich über die Zeit hinweg entwickeln. Diese dynamische Natur von Konflikten wird jedoch in der bestehenden Forschung zu Sanktionen und Verhandlungen nur unzureichend berücksichtigt. Bisherige quantitative Studien in diesen Bereichen basieren hauptsächlich auf statischen Modellen, die keine ausreichenden Erkenntnisse über die dynamische Interaktion zwischen den involvierten Akteuren zulassen und den dynamischen Kontext der Konfliktentwicklung vernachlässigen.

Diese Dissertation erweitert die bestehende Literatur indem sie die zwei Felder der Sanktions- und Verhandlungsforschung kombiniert und dabei die dynamische Natur von Konflikten berücksichtigt. Dafür wird ein dynamisches, akteurorientiertes Simulationsmodell eingeführt und mit Hinblick auf eine Fallanalyse zum Iran-Atomstreit diskutiert.

Die Resultate zeigen, dass Sanktionen die Dynamik von Konflikten beeinflussen können. Verschiedene Faktoren des Sanktionsmechanismus können dabei zu einer Eskalation beitragen. Des Weiteren zeigen die Ergebnisse, dass durch solch eine Konfliktentwicklung eine Einigung attraktiver wird und zur Akzeptanz einer Verhandlungslösung führt, die vor der Eskalation nicht akzeptabel war. Die Resultate zeigen aber auch, dass solch eine Einigung oft mit höheren Kosten verbunden ist als früher abgelehnte Verhandlungslösungen.

Diese Dissertation liefert Erkenntnisse über den Einfluss von Wirtschaftssanktionen auf die Konfliktodynamik und stärkt das Verständnis über das Entstehen von Verhandlungslösungen aus Konfliktsituationen. Aus einer praktischen Perspektive hebt sie weiter die Wichtigkeit hervor, Mechanismen zu finden, welche die Überwindung einer Eskalation ermöglichen und welche frühzeitige Verhandlungslösungen begünstigen.



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# 1. Introduction

Conflicts are an inherent part of human interactions and hence of international politics (Bercovitch, Kremenjuk, & Zartman, 2009). Consequently, there is a constant need to find appropriate ways of dealing with conflicts and working toward conflict resolution. A better understanding of such measures can help prevent violence and promote a more stable world.

The two instruments of economic sanctions and negotiations are building the cornerstones of nonviolent reactions to many geopolitical challenges. The use of economic sanctions, as an alternative to military intervention, has significantly increased in recent decades (Hufbauer, Schott, Elliott, & Oegg, 2009; Morgan, Bapat, & Kobayashi, 2014). Thereby, economic sanctions have increasingly shaped the development and dynamics of underlying conflicts. Complementary to such coercive means, which are intended to force the other side to give-in, negotiation is the single most important strategy in international conflict resolution. In this process, a mutually acceptable agreement is sought, providing a long-lasting and comprehensive solution to a conflict.

A prominent example of such a course of action is the Iran nuclear dispute. This conflict regarding Iran's nuclear activities lasted for years and led to extensive economic sanctions against Iran by the international community. Over the last several years, the United States, United Nations Security Council, and European Union imposed numerous sanctions to disincentivize Iran's nuclear activities. At the same time, Iran continually increased its nuclear enrichment capabilities. Only after years of escalation, it became possible to resolve this conflict through negotiations. This case is not only important from the perspective of international security and regional stability, but also because its analysis can provide insights about economic sanctions, negotiations, conflict dynamics, and their influence on conflict resolution. It is important to study how these elements of pressure, concession, and negotiation work and how they affect each other.

Despite plenty of research on economic sanctions, their underlying

mechanisms and effectiveness remain unclear and intensely debated (e.g., Hufbauer, Schott, & Elliott, 1990; Pape, 1997; Drury, 1998; Drezner, 2003; Cox & Drury, 2006; Bapat, Heinrich, Kobayashi, & Morgan, 2012). In this debate, economic sanctions are generally seen as a coercive means to achieve unilateral policy change in the target country. But, their influence on conflict dynamics and on reaching mutually negotiated agreements has not been a focal point of discussions. Despite the rather ambiguous conclusions regarding the usefulness of economic sanctions in the scientific literature, policy makers have continued to implement them (Morgan et al., 2014). Therefore, it remains an important challenge to understand why sanctions are implemented, how they work, and how they influence a conflict and its resolution.

Research on negotiation has made considerable progress over recent years, leading to important insights regarding influences, processes, and outcomes of negotiations. Furthermore, there is an increasing comprehension that not only the process of negotiation, but also the history of the underlying conflict affect the possibility of starting a negotiation and influence its outcome (e.g., Zartman & Faure, 2005a; Saunders, 1985).

However, surprisingly little research combines the two areas of sanctions and negotiations. Little attention has been given to the question of whether sanctions could be a tool for negotiations and how these mechanisms might interact. Furthermore, an examination of the dynamics between sanctions and negotiations demands methods that go beyond static observations. Existing theoretical models employ rather static, equilibrium-oriented approaches to examine the underlying mechanisms of economic sanctions (e.g., Eaton & Engers, 1992; Kaempfer & Lowenberg, 1988; Lacy & Niou, 2004; Whang, McLean, & Kuberski, 2013; Whang & Kim, 2015; Miyagiwa & Ohno, 2015). To better understand how sanction episodes work, there is a continued need to complement these static models with dynamic elements including, for example, feedback loops over many rounds and endogenous sanction choices. It is important better understand how sanctions could influence conflict dynamics and how this could affect the onset and outcome of negotiations. Moreover, such theoretical models should be tested against real-world cases.

This dissertation takes a dynamic look at economic sanctions and investigates their mechanism, influence on conflict, and relationship to a negotiated agreement. A formal model is developed and used to study the underlying mechanisms and draw conclusions about their functions



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and interactions. Hereby, the focus lies not only on the coercive forces of sanctions for unilateral concession, but also on their influence on conflict dynamics. The assessment of emerging patterns of escalation and stabilization is not only of interest in studying conflict itself, but also for the assessment of possible mutual negotiations, to understand how an agreement can arise and who can benefit from it. Furthermore, the results from this theoretical model are exemplified and discussed with regard to the Iran nuclear dispute. In addition to this new model, the case is also discussed with respect to the established graph model for conflict resolution (Hipel, Kilgour, & Fang, 2010). The combination of these two theoretical models with a comprehensive case study analysis allows for insights from different perspectives and contributes to a realistic understanding of the mechanisms of sanctions, negotiations, and conflict resolutions.

This dissertation makes several contributions to the literature of sanctions and negotiations. From a conceptual perspective, it combines the study of economic sanctions with international negotiation research, bringing together two of the most important concepts in international conflict response. Furthermore, this dissertation assesses the influence of economic sanctions on the dynamics and development of a conflict situation, where other research take a rather static perspective. From a methodological point of view, this dissertation introduces a dynamic, agent-oriented simulation model, where existing research almost exclusively relies on static, macro-level, causality-oriented models. In addition, it combines a formal model with an in-depth case study, which allows for drawing more realistic conclusions.

This dissertation is structured as follows: Chapter 2 has two parts that present theories and concepts. The first part introduces economic sanctions. It presents conceptual characterizations, historical developments, the main scientific discussions, and the mechanisms by which sanctions work. The second part presents the concepts of conflict dynamics, such as conflict, escalation, and negotiation. It also discusses important mechanisms and the relationships among the three concepts. Chapter 3 contains the formal models and the theoretical work of this dissertation. The first part starts with methodological remarks. The second part introduces the simulation model. It illustrates the underlying conflict structure, shows the importance of a dynamic approach, introduces the computational simulation model, and presents simulation results. The third part presents

an introduction to the established graph-model methodology. Chapter 4 presents an analysis of the Iranian nuclear dispute. The first part provides a case analysis. It introduces the background, assesses the development of the Iranian nuclear program, presents the history of sanctions against Iran, and concludes with a presentation of the negotiation process and the final agreement. The second part presents an exemplification of the simulation model to the Iran case and discusses its insights. The third part investigates the Iranian case using a graph model and presents its findings. Finally, Chapter 5 concludes the dissertation by discussing the overall findings, policy implications, limitations, and further research.

## 2. Theories and Concepts

### 2.1. Economic Sanctions

#### 2.1.1. Background

Sanctions are measures taken by countries against others, for political reasons to express disapproval with certain actions or situations. There exist a variety of sanction types, with diplomatic, economic, and military sanctions being the most common in international relations. Diplomatic sanctions are political measures that reduce diplomatic interactions and connections, such as the cancellation of high-level government meetings or the withdrawal of diplomatic missions. Economic sanctions are measures that are related to trade and finance that reduce economic exchange. And, military sanctions can range from carefully targeted military strikes to more extensive military operations. This dissertation focuses on economic sanctions and uses the term “sanction” primarily within this domain.

Economic sanctions are trade-related and finance-related penalties a country or a group of countries (e.g. an international organization) levies against a target country, group, or individual.<sup>1</sup> Even though small conceptual differences exist between economic sanctions, economic coercion, and economic statecraft, these terms are used interchangeably in this dissertation. The technical differences between these three concepts concerns their distinction: economic sanctions are mainly seen as trade-disrupting measures, economic coercion includes further softer measures such as the withdrawal of foreign assistance, and economic statecraft includes positive economic inducements, in addition to negative sanction measures.

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<sup>1</sup>The terms embargo and boycott, which are not used so often anymore, make a statement about the direction of trade disruption. While an embargo stands for an interruption of exports to a target country, a boycott means that the imports from a target country are suppressed.

In international politics, economic sanctions are used as a tool to coerce a target government toward a particular requested response or behavior. Such measures are a deliberate interference into the decision-making process of another sovereign government. They are typically a stronger policy instrument than other diplomatic interventions but are less aggressive than the immediate use of military force.

The mechanisms of economic warfare are not new and have been used for centuries. One of the first verified examples is the ancient Athenian boycott of Megara, which influenced the start of the Peloponnesian War. Furthermore, the old trading empires, such as the Netherlands, Portugal, and Venice, used their economic power as a means to subversively influence their enemies (Drezner, 1999). In modern days, economic sanctions became more prominent as a consequence of growing economic interlinkages and dependencies. This has been especially true since the First World War. In the beginning of the twentieth century, in light of the horrors of the First World War, US President Woodrow Wilson saw economic sanctions as an adequate, peaceful, and powerful tool for future international politics (Padover, 1942). This was reflected in the legal structure of the League of Nations, which launched the collective use of economic sanctions as a means of deterring aggression. But, with the failure of the League of Nations to prevent the Second World War, the use of economic sanctions by international organizations became rare. Nevertheless, individual countries and especially the United States (US) have used it extensively as a tool in foreign politics. Even though the United Nations Security Council (UNSC) issued economic sanctions only twice in its first 45 years of existence (against Southern Rhodesia and South Africa), the collective use of these sanctions increased substantially after the end of the Cold War (Hufbauer et al., 2009; Morgan et al., 2014).

Sanctions can be divided into unilateral and multilateral sanctions. Unilateral sanctions are imposed by one sanctioning state against a target and are governed by the domestic law of the sanctioning country. Multilateral sanctions are imposed by several states and are determined by either the United Nations (UN) or an intergovernmental organization (e.g., the European Union).

In the case of the UN, the UNSC is responsible for all measures that aim to maintain or restore international peace and security. Article 41 of the United Nations Charter mentions a broad range of sanction measures, which do not involve the use of armed force, to pursue the objectives of

the UNSC.<sup>2</sup> Even though UN sanctions are governed by an international legal framework, they are enforced by individual member states.

Since 1966, the UNSC has established 26 sanction regimes, in Southern Rhodesia, South Africa, the former Yugoslavia, Haiti, Iraq, Angola, Sierra Leone, Somalia, Eritrea, Liberia, The Democratic Republic of the Congo, Côte d'Ivoire, Sudan (twice), Lebanon, The Democratic People's Republic of Korea, Iran, Libya (twice), Guinea-Bissau, Central African Republic, Yemen, South Sudan, Mali, and twice against ISIL (Da'esh), Al-Qaida and the Taliban (United Nations, 2018). These sanction regimes were mostly established to support the settlement of conflicts, nuclear non-proliferation, and counter-terrorism.

As economic sanctions were used more frequently starting in the 1990s, the negative effects of sanctions on the civil population of a target country became more obvious. The comprehensive sanctions against Iraq and their severe harm to the population led to the understanding that such negative externalities had to be limited. This led to the development and use of more targeted sanctions, which are intended to directly affect responsible individuals, companies, and organizations, or to limit themselves to some key commodities. Examples include travel restrictions, the freezing of funds and other assets, investment restrictions, or trade barriers for specific goods such as luxury items, diamonds, oil, or weapons. So-called smart sanctions are intended to hurt elite supporters of the targeted regime, while theoretically imposing minimal hardship on the mass public. Economic sanctions are now a widely used tool in international politics and have become one of the key elements of Western response to many geopolitical challenges.

### **2.1.2. Scientific Discussion**

As sanctions developed to become an important tool in international politics, research started with a focus on qualitative case studies of specific

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<sup>2</sup>Charter of the United Nations, Chapter VII - Action with respect to Threats to the Peace, Breaches of the Peace, and Acts of Aggression, Article 41: "The Security Council may decide what measures not involving the use of armed force are to be employed to give effect to its decisions, and it may call upon the Members of the United Nations to apply such measures. These may include complete or partial interruption of economic relations and of rail, sea, air, postal, telegraphic, radio, and other means of communication, and the severance of diplomatic relations."

sanction events (e.g., Galtung, 1967; Hoffmann, 1967; Barber, 1979). This work was more of a documentary nature than on theory building and the testing of general hypotheses. Nevertheless, it illustrated and provided an in-depth understanding of the examined sanction episodes and critically discussed the effectiveness of economic sanctions. Researchers further developed a theoretical background and a distinction of economic sanctions from other economic policy tools (Daoudi & Dajani, 1983). They also discussed the wide range in which sanctions are used to promote national interests in comparison to alternative policy options (Baldwin, 1985).

Empirical research started with Hufbauer et al. (1990), who published one of the most widely cited works in the sanction literature. Their study analyzed more than 110 sanctioning episodes and established the ground rules for many subsequent studies with an empirical research approach. The most important discussion question was whether sanctions are an effective and efficient foreign policy tool. Scholars began utilizing theoretical and analytical models to explain and predict the necessary conditions under which sanctions should succeed or fail. Hufbauer et al. (1990) measured the success of sanctions episodes and claimed that 34 percent of the examined cases were successful in leading to political change in the target country. Other studies, mainly based on empirical examination, concluded that sanctions might not be an effective tool to unilaterally change the behavior of target states (Drury, 1998; Haass, 1997; Pape, 1997).

Some scholars pointed out that sanctions might serve different goals such as influencing domestic politics, sending diplomatic signals, or functioning as a tool in negotiations (Drury, 2005). They questioned the definition of success in quantitative studies and highlighted a selection bias when looking only at cases where sanctions had been implemented while neglecting cases in which just the threat of sanctions led to a change in the target country (Morgan & Miers, 1999; Drezner, 2003; Morgan et al., 2014). They argued that, if sanctions were likely to be successful, the threat of such sanctions could have an effect, and states that ignored the threat were unlikely to change their behavior after they were sanctioned (Lacy & Niou, 2004).

In recent years, empirical research has tried to move beyond the assessment of success and has focused more on the function, influencing factors, and intended or unintended side effects of sanctions (e.g., Weiss, 1999;

Andreas, 2005). Thereby, the discussion about more targeted, so-called "smart sanctions", emerged (e.g., Tostensen & Bull, 2002; Drezner, 2011).

A different research strand has employed formal models to study economic sanctions. These models have focused mainly on game-theoretic analyses, building on Nash's elaboration of the threat concept in the two-person cooperative bargaining problem (Nash, 1953). Black and Cooper (1987), who formulated a theoretical sanctions framework to investigate the level and distribution of welfare in a target country, published the first attempt of an analytical sanction model in international relations. Tsebelis (1990) used a game-theoretic approach to assess the effectiveness of economic sanctions. Subsequently different scholars used game theory and formal models to study the characteristics of sanctions (Eaton & Engers, 1992, 1999; Lacy & Niou, 2004; Morgan & Miers, 1999; Smith, 1995). Their research showed that, in a game of complete information, sanctions should never be imposed, and they confirmed the importance of threats, thus opening the field for further studies.

Different models exist that consider specific aspects of sanction problems. These models study sanctions as a public choice approach (Kaempfer & Lowenberg, 1989), analyze different relations between the sender and target (Drezner, 1999), focus on the role of issue linkage (Lacy & Niou, 2004) and information exchange (Verdier, 2008), evaluate the success of coercion and threats (Krustev, 2010; Whang et al., 2013), or use the model as a structural estimation, by employing a game-theoretic method in a statistical model (Whang, 2010).

However, these empirical studies and models use a mainly static perspective in sanction episodes. There is a need to develop further insights by utilizing more dynamic models and to analyze sanction interactions over many rounds. This information will lead to a better understanding of the mechanisms that make sanctions successful. It will also promote a study of their influence on other domains, such as negotiations, and the role they play in reaching a mutual agreement.

### **2.1.3. Working Mechanisms**

Sanctions are an important, yet controversial, tool in international politics. There are diverse motives for the use of sanctions, different mechanisms by which they are expected to work, and various possible unintended side effects. In a classical understanding, sanctions are used to achieve a

policy change in a target country. They attempt to achieve such change through increased pressure, anticipating that the targeted government will alter its policy or that the affected general population will rise up against the government to cause a policy change or replacement of the government. This approach is expected to work in an appropriate way without the immediate use of military force.

Research shows that the underlying mechanisms of economic sanctions are not always straightforward and that the question of effectiveness and efficiency of economic sanctions is not easily answered. It remains a nontrivial and important debate. If sanctions are to be useful, there could be an opportunity for world politics to become less violent and military confrontations to be reduced. If, however, sanctions hardly ever achieve their intended objectives, but lead to unacceptable hardship for the population of a target country, their use has to be critically questioned.

Sanctions are used for different reasons. The UNSC established sanction regimes to force cooperation with international law, to contain threats to peace within geographical boundaries, or to condemn distinct actions or policies. Specific reasons include the support of peaceful transitions, deterrence of non-constitutional changes, constraint of terrorism, protection of human rights, and promotion of nuclear non-proliferation. Unilateral sanctions are issued on somewhat broader grounds, but remain largely within this circumscription.

The primary motive for imposing sanctions is to coerce a target into a particular avenue of response. However, there are other motives for the use of sanctions. Important aspects can be found in the domestic politics of the sanctioning country. As public resistance to military interventions increases, policy is turning more toward the use of sanctions. Even though they might be only an imperfect and ineffective substitute for forceful actions, they avoid the accusation of not doing anything at all. The public still sees the use of sanctions as acting against security threats or violation of international law.

Furthermore, sanctions can also act as a wider threat by the sender government. Not only is the target of the sanctions being forced to comply with requested behaviors, but other countries are being challenged to observe that misbehavior is not tolerated and will be retaliated against. Following this line of argument, it can further be reasoned that sanctions also act as a signal toward the target. In a world of imperfect information, such signals can point out the seriousness of the target's misbehavior and



the intention of the sender to act against that behavior. Such signaling is not unusual and can, for example, be seen in the mobilization of troops or in the conduct of a military maneuver. If sanctions were symbols, their direct effectiveness would probably be secondary to the sanctioning country. Instead, the importance of sanctions lies in their capacity to act as effective signals. To work as a credible signal, sanctions have to be recognized by the other side as a non-empty threat (cheap talk in game-theoretic terms). Therefore, an action that is costly for the sender helps to send a credible threat, because the sender is less likely to use such an expensive signal as a bluff (Schelling, 1960). Sanctions limit the ability of the sender country's economy to interact freely and, therefore, are also linked to economic costs for the target country. Thus, economic sanctions have the potential to work as costly and serious signals. Furthermore, already a credible threat of sanctions could lead to a policy change in the targeted country. Cooperation can be a stable outcome, if there is a prominent belief that it is best to avoid being sanctioned at all (Axelrod & Keohane, 1985).

Mechanisms also exist that speak against the usefulness of sanctions. Given the previously mentioned domestic reasons for the use of sanctions, their implementation might be halfhearted and erratic. Also, the target government could, under some circumstances, even profit from the sanction situation. This can happen through the emergence of a *rally around the flag effect* (Mueller, 1970), in which the population unites behind the government in the event of external pressure. A bad economic situation and even adverse social developments can be blamed on the sanction situation and ultimately on the aggression of the sender government. Finally, a sanctioned regime can further strengthen state control over the economy. While trade-oriented sectors are hurt by the sanctions, they can also strengthen the import substitution sector and lead to a more closed but eventually also more independent economy.

Moreover, sanctions can potentially be effective only if the sender (or a sender coalition) controls a large share of the sanctioned goods. Otherwise, it might be easier to evade sanctions by trading with a party that does not participate in the sanctioning. Therefore, to implement such a sanction regime, a high degree of international cooperation is needed, which is not easily achieved. The incentive for not participating in the sanctions increases when a large sender coalition is involved, because the situation can lead to significant profit for the nonparticipating party,

which can be seen as a typical example of free-riding. Especially during the Cold War, one party was often willing to subvert a sanction regime, also for political reasons.

In addition to the possibility of unintentionally strengthening the sanctioned regime, other unintended consequences can occur. Sanctions can lead to severe humanitarian costs. Besides a decrease in per capita gross domestic product and increased unemployment, they can also lead to severe deterioration in public health (Gibbons & Garfield, 1999), negatively affect the human rights situation in the target country (Lopez & Cortright, 1997; Peksen, 2009), and even contribute to the criminalization of the state, the economy, and civil society (Andreas, 2005). Furthermore, research showed that the use of sanctions increased the probability for a military escalation of the conflict (Lektzian & Sprecher, 2007). To reduce such unintended side effects, sanctions are often designed to directly target the responsible individuals and keep the use of broad and comprehensive sanctions to a minimum.

These considerations decrease the perceived effectiveness and efficiency of economic sanctions. But, two points are worth mentioning. First, the use of sanctions has to be compared to alternative policy options and their possible negative consequences. Sanctions can be a preferred tool due to a lack of feasible alternatives. Second, the practical reality of sanctions is often not as ambitious as in theory. Rarely is there an expectation that sanctions alone will lead to a regime change or a complete change in policy. Moreover, the goal is often to stop a certain development or to steer it in a particular, more favorable, direction. Taking this narrowed ambition into consideration, sanctions could become more successful.

Sanctions could even work in an additional manner, as discussed in the later chapters of this dissertation. They could work as a tool in negotiation and play a role in the possibility of reaching a mutual agreement.

## 2.2. Concepts of Conflict Dynamics

This section introduces the concepts of conflict, escalation, and negotiation and illustrates the interlinkages between them. These three concepts play a fundamental role in understanding the development of a conflict and studying its dynamic.

### 2.2.1. Conflict

A conflict is the perceived incompatibility between different interests or values that can occur in any system of interaction, ranging from the individual to the international level. It is a ubiquitous and unavoidable feature of human existence, which often has to be managed or resolved to avoid a dysfunctional influence on the system (Deutsch, 1973).

A social conflict occurs in a social interaction between two or more actors, who are using power in an effort to attain scarce or incompatible objectives and preventing the other side from attaining them. International conflicts are a form of social conflict that are distinguished through the involved actors. Such conflicts are waged between states, within states, and by non-state actors (e.g. militias, insurgencies, terrorist organizations, and private military contractors). The enduring political disagreement between nation states, the proliferation of internal conflicts, terrorism, and many more topics in international relations have led to a vast interest and corresponding literature on international conflicts and its resolution (e.g., Mitchell, 1981; Wallensteen, 2002; Bercovitch et al., 2009).

Often it is not possible to stop the occurrence of conflict but attempts are made to minimize its negative expression. Conflicts can sometimes also have positive effects (Deutsch, 1973), like the stimulation of positive change, the solving of problems, or the improvement of relationships. However, the negative consequences of conflicts and especially their violent expression make it necessary to manage and resolve them. This need for conflict management can further be reinforced by concerns about an escalation of the conflict. Typically, conflict escalation can take one of two main directions: horizontal and vertical. Horizontal escalation refers to a spatial spreading of the conflict, for example to neighboring countries. Vertical escalation refers to an increase in intensity and negative impact of the conflict. Concerns about conflict escalation can furthermore give a third party a reason to initiate and undertake such attempts to manage or resolve a conflict.

Different concepts and approaches exist to handle conflicts. Prominent examples are conflict management and conflict resolution. Conflict management is an effort to control or contain an ongoing conflict with the aim of making it less damaging for the parties that are directly involved (Bercovitch & Fretter, 2004). The emphasis lies on the management of the negative effects of a conflict and not so much on the solving of

the underlying causes. Conflict resolution is often more ambitious than conflict management by trying to solve the underlying issues. It can be understood as actions to limit and reduce the level of violence and to achieve some understanding on key issues (Wallensteen, 2002). Often, such actions and understandings are then documented in a joint agreement. Negotiation is one strategy for conflict resolution, in which an exchange of concessions can take place and an agreement can be found through a joint decision-making process.

It is worth noticing that conflicts, like negotiations, are of a dynamic rather than a static nature. They evolve with the interaction among the involved parties and are, therefore, often complex, interlinked processes.

### 2.2.2. Escalation

Escalation is the process of an increase or rise in intensity. Conflict escalation is an ongoing increase in conflict intensity, leading to a change in conflict relations. Thereby, an important focus lies on the changing nature of the conflict. A gradual intensification does often not only lead to a quantitative but also to a qualitative change in conflict. Such a process typically originates from the situation that one or both sides exercise power over the other with the intent to change the other party's behavior. It can be understood as a tactical step that is embedded in the development of conflicts (Schelling, 1960, 1966).

The initial intent for an increase in pressure is often to hurt the other side in order to force a change in behavior. This pressure can result from direct actions, or it can be expressed in the form of threats, as an intention to take direct actions. The aim of such an action can be a unilateral concession of the other side to give in. The aim can be to achieve a partial change of behavior such as bringing the other side to the negotiation table. An increase in pressure is sometimes used less strategically simply to punish or retaliate. Altogether, escalation is intended to raise the costs for the other side to keep it from holding out or seeking to win the conflict. But at the same time, escalation often increases the costs for the initiating party as well. This happens not only through a possible retaliation but can also result as added pressure is normally attached to expenditures and is usually not free of costs.

Escalation can happen unilaterally but more often it is a responsive interaction between the parties, leading to a two-sided relation. Such

a competitive climb in a conflict can be perfectly rational, at least up to a certain point. Reacting toward pressure with counter pressure can have different motivations. It can be done to halt the previous escalation by increasing the costs of further escalation, it can be motivated by the intention to retaliate, or it can be driven by the intention to get the other party to back down. All of these motivations are reasons for a deliberate increase in pressure.

Besides the deliberate increase in pressure, other factors exist that increase the likelihood of escalation. The literature on conflict escalation highlights “cognitive factors”, such as judgment and perception biases, as possible important underlying drivers of escalation (Zartman & Faure, 2005b). One of the most important drivers is seen in the aim to retrieve losses from previous expenses, the belief that one could recover the initial investment by investing even more. Furthermore, overconfidence can push toward escalation if one party is convinced about its own influence, but the other side does not react as expected. Moreover, incomplete information, misperception of the conflict and the other side, and unclear consequences of actions can additionally lead to escalation. All this is further intensified in the case of state actors because decision makers often do not or cannot admit initial mistakes or wrong assessments. There is a strong pressure for consistency in their own actions that make it difficult to change policy and can promote escalation.

The two sides might push the escalation in the expectation that just one more increase in pressure will lead to the desired change in the behavior of the other party. Yet, the other side makes the same calculation, which then leads to another round of escalation. If all information would be available and the parties would know how much it would take to bring the other side to give in, the suitable amount of coercion would simply be a matter of calculation. In such a situation, it might never come to an escalation. Already, the threat of using a coercive means could produce the same result, potentially being cheaper for both sides.

In its simplest form, intensification of a conflict proceeds until it does not go any further and someone capitulates. For example, the opponent might change its behavior as pressure becomes too high, or the initiator might realize that the costs outweigh the desired benefits.

In addition, escalation does in some cases stop without one party giving in. Such an outcome of escalation that does not produce a winner or loser is called a deadlock (Zartman & Faure, 2005b). Further escalation is

blocked, but it is also not possible to de-escalate. The parties are stuck in a state of uncertainty between conflict and negotiation, keeping the other side from winning even if they also keep their own side from winning. Only when all parties perceive themselves in a mutually hurting stalemate and see the possibility for a way out, for example through negotiations, is the situation ripe for resolution (Zartman, 2008).

Under some instances, different processes can break the escalation process and even lead to a negotiated agreement. One example is when one side feels fear or fatigue about the further costs of escalation and a corresponding withdrawal. Furthermore, ending up in a mutual damaging stalemate, a deadlock that hurts both of the parties, can stop the escalation without de-escalating it. Moreover, a change in stakes, parties, or attitudes leads to a change in conflict and can potentially stop escalation. Learning processes, for example, through obtaining new information or revising an initial assessment, can lead to a new evaluation of the conflict and potentially break an ongoing escalation. Additional measures and arrangements can help to break escalation. Examples include confidence-building measures (CBMs) or disengagement from the process to establish a pause or truce that can lead to a reappraisal and reevaluation of the positions.

Therefore, it seems that escalation can change the conflict in two directions. First, it can intensify and worsen the conflict. Second, it can lead to the start of negotiations (Zartman & Faure, 2005a). Escalation, as a concept in itself, includes the idea of the threat of future escalation, which would involve even higher costs. If this situation is realized by both sides, negotiations are possible. Under specific circumstances, escalation can enable, accelerate, or generate an opportunity for negotiation. In other cases, escalation can inhibit the occurrence of negotiation.

### 2.2.3. Negotiation

Negotiation describes a voluntary exchange between two or more parties that aims to reach a mutual agreement. It is a process in which parties try to combine their divergent positions into a compromise (e.g., Pruitt, 1981; Raiffa, 1982).

Under certain circumstances, negotiation can provide an end to conflict escalation by opening a dialog. Escalation can even work as a catalyst to think about negotiation as an alternative to further conflict or unilateral

concession. This can happen when a negotiated agreement becomes more desirable when sunk costs increase as a result of escalation. If expenses are getting higher, negotiation provides the possibility that at least some of these costs can be retrieved and some benefit can be achieved. Furthermore, parties can possibly save face by going into negotiation as an alternative to giving in.

An escalation can even be initiated with the purpose of starting negotiations by producing a power imbalance to force the other side to the negotiation table while giving the initiator a potentially stronger negotiation position. It can confirm an asymmetric result, seek to cut costs of conflict by halting further escalation, or intend to work toward a solution to the problem itself. But, finding a way, on how to get out of the escalation and into a negotiation remains a challenge. All in all, the process of escalation can, under some circumstances, be seen as pre-negotiation behavior.

The prologue of negotiation, including the structure and dynamics of the underlying conflict, is an important factor that influences the possibility of starting a negotiation and can also affect its outcome. Therefore, it is important to look at the circumstances under which an agreement came into being in addition to analyzing the result of the negotiation. Negotiation scholars have pointed out the importance of also studying these pre-negotiations (Saunders, 1985; Stein, 1989; Zartman, 1989) and the ripeness of a conflict for negotiation (Zartman, 2000), in addition to the pure analysis of the negotiation process (e.g., Lax & Sebenius, 1986; Raiffa, 1982). Such considerations are important because bringing the parties to the table and getting them to talk with each other is an inevitable precondition for negotiation. Moreover, it is important to study such processes because they can sometimes be among the most difficult parts in reaching an agreement (Saunders, 1985; Zartman, 1989).

The influence of pressure and escalation on negotiations is not fully clarified. It seems evident that a de-escalation process is essential to end a conflict and to start talking about a cooperative solution (Kriesberg, 1987; Mitchell, 1991). Removing obstacles for negotiation talks (Saunders, 1985), redefining the relationship (Poitras, Bowen, & Byrne, 2003), and establishing mutual trust (Poitras & Bowen, 2002) between the parties are critical tasks to facilitate the initiation of such a process. However, it is also argued that pressure is a critical factor that can increase the willingness to negotiate (Poitras & Bowen, 2002; Poitras et al., 2003). Such

pressure can be domestic (Kriesberg, 1987), allied (Stein, 1989), or external (Wallihan, 1998), as well as structural, such as time pressure (Druckman, 2001). Even though such pressure can, under certain conditions, promote the willingness to negotiate, it is further argued that, under different conditions, pressure can have an opposite effect and worsen the willingness to negotiate (Zartman, 2000).

The question of how pressure influences negotiation remains important. However, scholars tend to overlook the development of the conflict as an imminent source of pressure, when looking at the negotiation process (Zartman & Faure, 2005a). There is yet little analysis on negotiation within the dynamic context of conflict, even though negotiations can be understood as a response to conflict movements (e.g., Druckman, 2001). Especially the questions of when, how, and why the willingness to negotiate shifts from a negative effect of pressure to a constructive one, is not extensively discussed in the literature.

To study the dynamics of conflict and assessing its influence on negotiation, this study builds upon the work of escalation and negotiation in international conflicts (e.g., Zartman & Faure, 2005b). It expands this literature by a formal description of the mechanisms of escalation and agreement in a conflict interaction.



# 3. Formal Models

## 3.1. Methodological Remarks

The study of conflict is interdisciplinary and has a long tradition in numerous areas of science such as political science, economics, and psychology. Various disciplines have acquired a diverse set of methods and made considerable progress by using them to study conflicts. On the level of state actors, political science has made a substantial contribution in analyzing many aspects regarding interstate and intrastate conflicts. An important part of these findings is based on empirical research, with the aim that this collection of data can accumulate into a theory. The study of aggregated implications, however, remains difficult. In particular a focus on the process of conflicts requires different methodological approaches that consider its dynamic nature.

Conflicts are dynamic processes that are comprised of multiple interactions between diverse actors with a complex underlying structure. Studying such structures and patterns is important for understanding the dynamics and development of a conflict. This is not only important for conflict analysis but also for studying the emergence of possibilities for a negotiated solution. However, comprehending such an underlying structure in an existing conflict is often complex and not easy to achieve.

This chapter expands the existing theoretical work on sanction episodes by introducing a sequential, repeated computational model to study interactions between a sanctioner and a sanctionee in a conflict situation. A simulation methodology, based on autonomous interacting agents, is used for this analysis. This model allows for the study of dynamics in such a relationship not only for one encounter but over many rounds of interaction. In addition to this new model, the chapter further provides an introduction to the established graph-model methodology. An application of both these models is presented in the next chapter.

#### **3.1.1. Modeling**

To study selected parts of reality, scientific study relies on the representation of these phenomena in the form of models (Hacking, 1983). A model is a simplified representation of the real world. It is an abstraction of the phenomena of interest that is too complex to be studied directly. To reduce complexity, the model is limited to the essential influencing factors and is never a complete representation, but instead lags behind reality in every aspect, except for understandability.

Despite, or precisely because of, its simplification of reality, modeling is one of the main tools in science and provides a central unit of scientific theorizing. Through its reduction of complexity, modeling can help to define, quantify, understand, visualize, or simulate the phenomena of interest. Thereby, it allows for a better comprehension of reality and enhanced communication.

Theoretical models are often expressed using formal, mathematical concepts and terms. If a phenomenon involves a large number of variables, nonlinear relationships, as well as interaction and feedback loops, the description in everyday language is virtually impossible and leads to problems of ambiguity. The use of mathematical language, however, increases the logical accuracy of the description and allows the employment of available mathematical tools. Usually, a range of such tools exist that can be helpful in studying the phenomena of interest.

Even though formal models rely on proving propositions or solving equations, the key, and difficulty, in using a model lies in its design. Difficulties arise in the identification of important influencing factors and in designing abstract, simplified representation of these factors because the selected structure and assumed simplifications of reality determine which equations are set up in the first place.

#### **3.1.2. Simulation**

Formal mathematical models can be used in various ways to gain insights about the subject matter. The method that is used depends on the field of study and even more so on the objective of the analysis.

In the field of social science, a long tradition exists in using rational choice and game theoretic models to analyze the interaction of actors. These methods follow an analytical approach that focuses on static equi-

librium outcomes. Therefore, these models have to be narrowly defined and simplified to ensure analytical solvability because any analytical solution becomes increasingly difficult if the model includes parallel processes, nonlinearities, or heterogeneous actors. Especially for the study of repeated interactions, an analytical solution concept is not always suitable, because an infinite variety of behavior patterns can be observed in equilibrium (Fudenberg & Maskin, 1986; Wen, 2002).

However, if the focus of an analysis is on the process, computational models and simulations are a better fit. They allow the expression of ideas about processes or mechanisms in a flexible yet precise way (Gilbert, 1999). A simulation can be understood as the execution and calculation of a model, which replicates the system of interest through its dynamic processes. It allows to assess the effects of different initial conditions on the process and its final result. Simulations are well-suited to handle complex problems and can often go further than analytical methods. In political science especially, simulations can deal with problems that are analytically intractable within other modeling traditions (Johnson, 1999).

Modeling and simulation can be understood as counterfactual methods that enable the study a multitude of “what if?” questions. They allow to build a construct based on rules and to evaluate the results that emerge from these rules. In a broad sense, simulation can be seen as a thought experiment (Axelrod, 2007) to enable exploration of the implications of the chosen assumptions. The goal is to explore decision-making and information processing with no focus on equilibrium but rather on the process of adjustment.

For these reasons, there is an ongoing transition in the social sciences, from rational actor models to agent-based modeling, and from top-down macro decision-making to bottom-up micro-simulation (Billari, Fent, Prskawetz, & Scheffran, 2006). Where other approaches seek to understand why specific rules are followed by the involved actors, the agent-oriented model defines micro-based rules of behavior and assesses whether they can explain macroscopic patterns. The emphasis is on the explanation rather than on the prediction of behavior. In such a model, individual agents act according to rules, which can be simple or complex, fixed or adaptive, deterministic or stochastic. Classical utility optimization is just one of many different rules (Billari et al., 2006).

Because the use of models can be helpful for theory building (Clarke & Primo, 2012), this work aims to develop a theoretical model to study con-

flict interactions. This model can provide insights regarding underlying mechanisms and help to assess pathways, under which conflict escalation can lead to one-sided concession and a cooperative negotiation.

The use of a computational, agent-oriented model is particularly useful in this analysis for two reasons. First, computational, agent-oriented models allow the analysis of complex systems. In the case that is presented in this dissertation, complexity emerges due to multiple interactions and different underlying rules for these actions. Second, agent-based models enable the study of the underlying casual mechanism of a conflict. Such systematic process tracing goes beyond the models that estimate relationships within an input-output framework and allow for the further study of underlying reasons for conflict dynamics. Axelrod (1997), Cederman (1997), and Miller and Page (2007) provide a more general discussion of the advantages and disadvantages of agent-based models in conflict analysis.

## 3.2. Simulation Model

### 3.2.1. Conflict Structure

To study the interaction between a sanctioner and a sanctionee, a model is introduced, which expands the existing literature in the analysis of economic sanctions and primarily follows their notation (e.g., Hufbauer et al., 1990; Eaton & Engers, 1992).

A conflict with two interacting players, the sender  $S$  (sanctioner) and the target  $T$  (sanctionee), is considered. Each player controls one variable. The sender controls the number of sanctions  $s$ , and the target controls the amount of the sanction-triggering topic  $t$ . This topic could be a nuclear program, human rights violation, pollution of the environment, specific trade policy, or anything else that the sender does not want.

The intention of the sender is to influence the behavior of the target. To achieve such a change in behavior, the sender has the power to harm the target by issuing sanctions. To contribute to a strategic policy, such a measure cannot be a best response and is only implemented to influence the other side (e.g. Schelling, 1960; Eaton & Engers, 1992). This means that such a coercive measure comes at a cost for the sender itself. While sanctions are designed to harm the target they are also negatively affecting

the sender, for example, because its economy can no longer freely interact. Cost-free or even beneficial measures that have a negative impact on the target are not considered.

The intention of the target is to increase the disputed topic. This topic is beneficial for the target, for example, because it increases its political power, provides financial benefits, or reduces costs. However, by definition, the topic has a negative effect on the sender.

The values of these two variables  $s$  and  $t$  therefore affect the utilities of the two players that they want to maximize. An increase in sanctions  $s$  affects both the sender  $S$  and the target  $T$  negatively, where as an increase in the topic  $t$  affects the sender  $S$  negatively but affects the target  $T$  positively.

From a more formal consideration, the sender  $S$  has a utility function of  $s$  and  $t$  that is described as

$$u^S(s, t) \text{ with } \frac{\partial u^S}{\partial s} < 0 \text{ and } \frac{\partial u^S}{\partial t} < 0. \quad (3.1.)$$

The target  $T$  has a utility function of  $s$  and  $t$  that is described as

$$u^T(s, t) \text{ with } \frac{\partial u^T}{\partial s} < 0 \text{ and } \frac{\partial u^T}{\partial t} > 0. \quad (3.2.)$$

The two functions are continuous in both variables and have the following monotonicity properties:  $u^S$  is decreasing both in  $s$  and in  $t$ ;  $u^T$  is decreasing in  $s$  and increasing in  $t$ .

### 3.2.1.1. One-time Encounter

In a one-time encounter, each party decides only once if they increase or decrease their controlled variable. In its simplest form, both players have two strategies: the sender can increase or decrease variable  $s$ , and the target can increase or decrease variable  $t$ . For illustrative purposes, the two variables are assumed to be either 1 or  $-1$ . The utility of the two players is defined by the linear function for  $S$  as  $u^S(s, t) = -a \cdot s - b \cdot t$  and for  $T$  as  $u^T(s, t) = -c \cdot s + d \cdot t$ , with  $a, b, c$  and  $d$  being positive numbers. Using these functions in the formulation of the payoffs allows for writing the sanction game in normal form as shown in Figure 3.1.

For player  $T$ , the strategy *increase*  $t$  is strictly dominant over the strategy *decrease*  $t$ , because  $d - c > -(d + c)$  and  $c + d > c - d$ . For player

		Sender	
		Increase $s$	Decrease $s$
Target	Increase $t$	$d - c, -(a + b)$	$c + d, a - b$
	Decrease $s$	$-(d + c), b - a$	$c - d, a + b$

Figure 3.1.: 2x2 matrix of the general sanction game

$S$ , the strategy *decrease  $s$*  is strictly dominant over *increase  $s$* , because  $a - b > -(a + b)$  and  $a + b > b - a$ . To make this more illustrative, Figure 3.2. shows the same game, where  $a = b = c = d = 1$ , which leads to the utility function  $u^S(s, t) = -s - t$  and  $u^T(s, t) = -s + t$ .

		Sender	
		Increase $s$	Decrease $s$
Target	Increase $t$	0, -2	2, 0
	Decrease $s$	-2, 0	0, 2

Figure 3.2.: 2x2 matrix of the sanction game

Both players have a strictly dominant strategy. The sender would always decrease the sanction  $s$ , and the target would always increase the topic  $t$ . Even if a third strategy is introduced, the option to leave the variable at the same level (in a one-time encounter similar to choosing a value of 0), the equilibrium does not change, as illustrated in Figure 3.3. The same strategies as before are strictly dominant, leading to a decrease in  $s$  and an increase in  $t$ .

		Sender		
		Increase $s$	Same $s$	Decrease $s$
Target	Increase $t$	0, -2	1, -1	2, 0
	Same $t$	-1, -1	0, 0	1, 1
	Decrease $s$	-2, 0	-1, 1	2, 0

Figure 3.3.: 3x3 matrix of the sanction game

It could be argued that a simultaneous decision does not properly reflect the nature of reacting toward an unwanted behavior and sanctioning such a behavior. Therefore, it is also possible to look at a sequential encounter, where first the target increases or decreases  $t$  and then the sender reacts by deciding whether to increase or decrease  $s$  as illustrated in Figure 3.4.

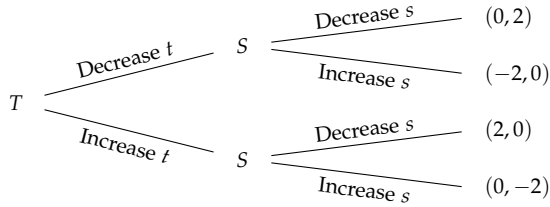


Figure 3.4.: Two strategies sanction game in extensive form

In this game and in the sequential interaction with three strategies each (illustrated in Figure 3.5.), the equilibrium still leads to an increase of the variable  $t$  and a decrease of the variable  $s$ .

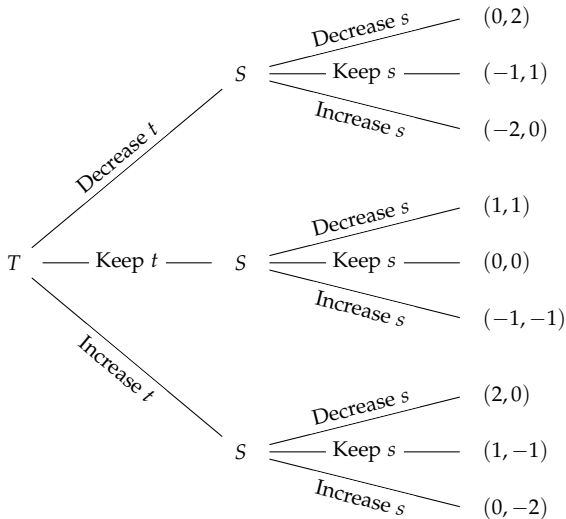


Figure 3.5.: Three strategies sanction game in extensive form

In this type of one-time interactions, sanctions would never be used, and unwanted behavior would always be increased. This result does not seem to reflect reality adequately, where sanctions are widely used. Therefore, such a model is probably not correct and other mechanisms have to influence the decisions in a conflict that involves the use of sanctions.

#### 3.2.1.2. Multiple Rounds of Interaction

It appears that a simple one-time interaction of a sanctioner and a sanctionee, as shown in the previous section, does not adequately represent the use of sanctions in reality. Sanctions and the sanction-triggering topic stand in a more complicated reciprocal relationship. Even though sanctions are adverse for the sender, they are implemented if an increase in topic can thereby be prevented. Moreover, the topic is probably not increased if the triggered sanctions are very harmful for the target.

One way to better reflect the occurrence of sanctions is therefore through the repeated interaction of the two players. Following such a structure, the sender  $S$  and the target  $T$  alternately determine their controlled variable  $s \in [0, 1]$  respectively  $t \in [0, 1]$  repeatedly over many rounds. By studying this type of interaction over a longer time, it is possible to cause and study the patterns that are observed in reality.

#### 3.2.2. Model Properties

This section introduces a sequential repeated computational model for the analysis of conflicts that involve the use of sanctions. This model represents the interaction between a sanctioner and a sanctionee not only for one encounter, but over many rounds. Simulating these interactions allows to study conflict dynamics and the emergence of observed patterns.

##### 3.2.2.1. Structure

The proposed computational model follows the logic of agent-based modeling, by defining the fundamentals for the interaction of the two players and studying the emerging effects on the system. It builds on a sequential repeated interaction between the sender  $S$  and target  $T$ , who alternately react to the circumstances and the actions of the other party.



The players determine their response according to specified rules, which can be organized into the following categories:

- *Beliefs*: Rules that represent the beliefs and expectations about future actions and reactions of the other party in response to the circumstances and own actions.
- *Optimization*: Rules that describe how the controlled variable is changed in response to the circumstances and the other party's actions, building on utility optimization.
- *Emotions*: Rules that represent a subjective emotional reaction, which leads to stronger opposition and less willingness for concession if the other side increases pressure.
- *Learning*: Rules that update the beliefs and expectations. Learning happens when the beliefs and expectations are proven wrong in the course of the interaction.
- *Negotiation*: Rules that represent negotiation solutions for the current state of the conflict.

The model follows a sequential repeated structure. The sanctionee starts first by observing the starting conditions. Following its rules, the sanctionee decides on the new value for its controlled variable and tries to optimize its utility under the assumption that this action will affect the future reaction of the other side. Thereafter, the sanctioner observes the circumstances and the changes made by the sanctionee. The sanctioner determines its new value for the controlled variable according to the corresponding rules (beliefs, optimizations, and emotions). In the subsequent rounds, the two sides sequentially assess the new situation, update their beliefs, and decide on their actions. In addition, they compare the current situation to a specific negotiation solution, which is only accepted if its utility is higher than the utility from the current situation for both players. Figure 3.6. shows a schematic illustration of the introduced model.

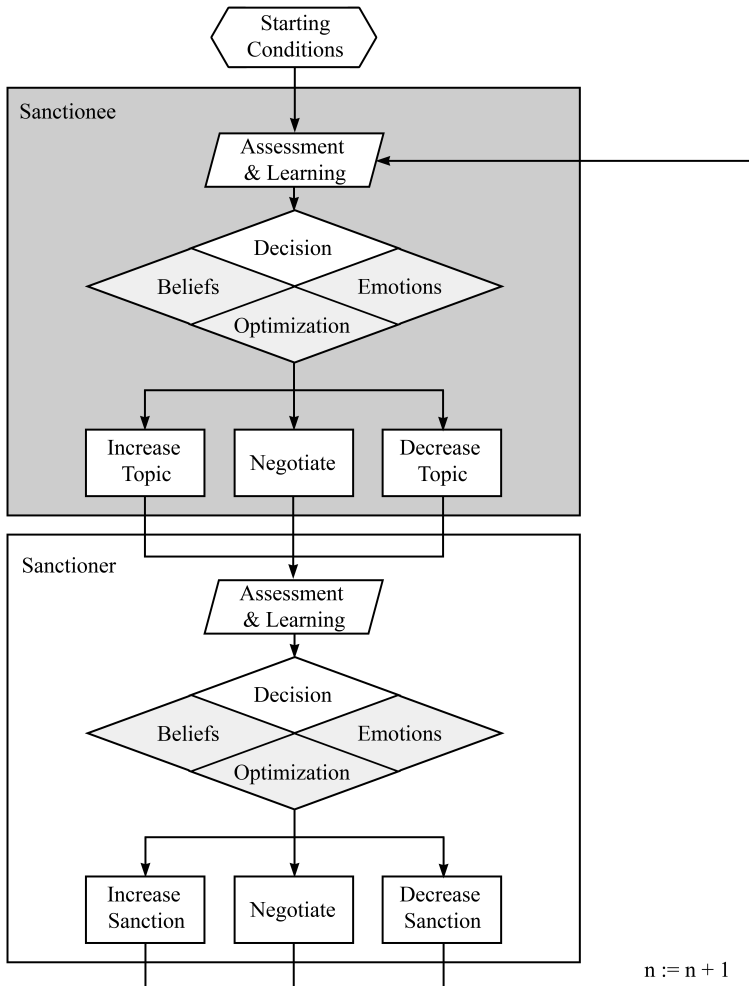


Figure 3.6.: Illustration of the sequential repeated computational model

### 3.2.2.2. Beliefs

Beliefs are a fundamental component in a repeated interaction. They represent the anticipation of how the other side will act in the future and also include the beliefs about the consequences of the own actions. Such anticipations are an important element for repeated actions over many rounds, because actions are often implemented with the aim to influence the behavior of the other side in the subsequent rounds. In the presented model, rules are defined that represent such beliefs and expectations about the future. These beliefs are modeled through a simplified comprehension of the sanctioning mechanism.

The sender  $S$  anticipates that a certain level of sanctions  $s$  will trigger a change in the action of the other side, the target  $T$ . The sender believes that, if the sanctions  $s$  will be big enough, the target  $T$  will decrease the variable topic  $t$ . The threshold where this is expected to occur is defined as  $\tau^T$  (threshold for  $T$ ). The sender  $S$  further believes that a lower level of sanctions  $s$  will not reduce the topic  $t$ . If the sanctions are just below  $\tau^T$ , it anticipates that  $t$  will stay the same. If the sanctions are even lower, below the threshold minus a security level ( $\tau^T - \sigma^T$ ), the sender believes that  $t$  would increase. Figure 3.7. (a) illustrates this belief about the influence of  $s$  on the change of  $t$ .

The beliefs of target  $T$  about the influence of its controlled variable topic  $t$  on the change of sanctions  $s$  is defined in an equivalent way. The target anticipates that a certain level of topic  $t$  will trigger a reaction by the other side. It believes that, if the topic  $t$  is too high, the sender  $S$  will increase its variable sanction  $s$ . The threshold where this is expected to occur is defined as  $\tau^S$  (the threshold for  $S$ ). The target  $T$  further believes that a lower level of the topic  $t$  will not trigger an increase in sanctions  $s$ . If  $t$  is just below  $\tau^S$ , the target anticipates that  $s$  will stay the same. If  $t$  is even lower, below the threshold minus a security level ( $\tau^S - \sigma^S$ ), the target believes that  $s$  would decrease. Figure 3.7. (b) illustrates this belief about the influence of  $t$  on the change of  $s$ .

These rules are implemented in the model in the calculation of the value for the expected topic  $t_x$  and the value for the expected sanction  $s_x$ . Both values and their calculations represent the beliefs of how the other side will change their variable in respect to the level of their own variable.

The expected topic  $t_x$  is calculated through the input of the current level of sanction  $s$ , the current level of topic  $t$ , the assumed value for

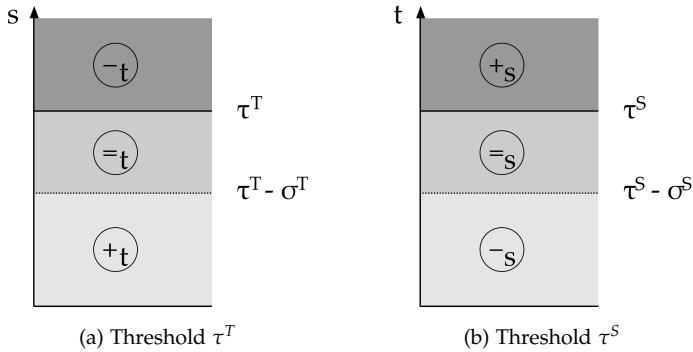


Figure 3.7.: Illustration of the thresholds  $\tau^S$  and  $\tau^T$

threshold  $\tau^T$ , and the assumed value for security level  $\sigma^T$ :

- If the current level of  $s$  is below  $\tau^T - \sigma^T$ , the topic will be increased, and  $t_x$  will be placed at the level of  $t + \Delta_t$ .
- If the current level of  $s$  is between  $\tau^T$  and  $\tau^T - \sigma^T$ , the topic will stay the same, and  $t_x$  will be placed at the level of  $t$ .
- If the current level of  $s$  is above  $\tau^T$ , the topic will be decreased, and  $t_x$  will be placed at the level of  $t - \Delta_t$ .

Algorithm 3.1. illustrates this procedure and how it is implemented in the model. In this process, the new value for the expected topic  $t_x$  is calculated depending on the region in which the variable sanction  $s$  is situated and its relationship to the other variables.

The expected sanction  $s_x$  is calculated in an equivalent way through the input of the current level of sanction  $s$ , the current level of topic  $t$ , the assumed value for threshold  $\tau^S$ , and the assumed value for security level  $\sigma^S$ :

- If the current level of  $t$  is above  $\tau^S$ , sanctions will be increased, and  $s_x$  will be placed at the level of  $s + \Delta_s$ .
- If the current level of  $t$  is between  $\tau^S$  and  $\tau^S - \sigma^S$ , sanctions will stay the same, and  $s_x$  will be placed at the level of  $s$ .

- If the current level of  $t$  is below  $\tau^T - \sigma^S$ , sanctions will be decreased, and  $s_x$  will be placed at the level of  $s - \Delta_s$ .

Algorithm 3.2. illustrates this procedure and how it is implemented in the model. In this process, the new value for expected sanction  $s_x$  is calculated depending on the region in which the variable sanction  $t$  is situated and its relationship to the other variables.

Algorithm 3.1.: Beliefs of  $S$  how a certain level of  $s$  will affect  $t$

---

```

input :sanction  $s$ , topic  $t$ , threshold
          $\tau^T$ , security level  $\sigma^T$ 
output:expected topic  $t_x$ 
initialization;
if  $s < \tau^T - \sigma^T$  then
  | topic will be increased;
  |  $t_x := t + \Delta_t$ ;
  | if  $\tau^T \geq s \geq \tau^T - \sigma^T$  then
  | | topic will stay the same;
  | |  $t_x := t$ ;
  | | if  $s > \tau^T$  then
  | | | topic will be
  | | | decreased;
  | | |  $t_x := t - \Delta_t$ ;
  | end
end
end

```

---

Algorithm 3.2.: Beliefs of  $T$  how a certain level of  $t$  will affect  $s$

---

```

input :sanction  $s$ , topic  $t$ , threshold
          $\tau^S$ , security level  $\sigma^S$ 
output:expected sanction  $s_x$ 
initialization;
if  $t > \tau^S$  then
  | sanction will be increased;
  |  $s_x := s + \Delta_s$ ;
  | if  $\tau^S \geq t \geq \tau^S - \sigma^S$  then
  | | sanction will stay the same;
  | |  $s_x := s$ ;
  | | if  $t < \tau^S - \sigma^S$  then
  | | | sanction will be
  | | | decreased;
  | | |  $s_x := s - \Delta_s$ ;
  | end
end
end

```

---

### 3.2.2.3. Optimization

Utility optimization is an important element that steers behavior. Especially in strategic interplay, it lays the foundation of action and repeated interaction. This action is carried out in such a way that it best fulfills and acts toward a desired state. Therefore, it can be seen as a representation of rational behavior. It is obvious that, in a more realistic consideration, this behavior must follow a bounded rationality. Accordingly, optimization could be understood as a bounded optimization that is limited by circumstances.

In the presented model, a reaction function for each player is defined that describes how the players change their controlled variables in response to the circumstances and the other party's action. These rules build mostly on utility optimization, where the players try to achieve a more preferable outcome. The players change their controlled variable if they anticipate that this change would lead to a better situation for them, considering also the beliefs about the caused reaction of the other side. Both variables are not freely set to new values without considering their history. Instead, the variables can only be changed incrementally, depending on their past levels.

The model builds on the utility structure defined in Section 3.2.1. *Conflict Structure* on page 22. The sender  $S$  has the utility function

$$u^S(s, t) = -\omega_s^S s - \omega_t^S t \quad (3.3.)$$

and the target  $T$  has the utility function

$$u^T(s, t) = -\omega_s^T s + \omega_t^T t. \quad (3.4.)$$

The factors  $\omega_s^S$ ,  $\omega_t^S$ ,  $\omega_s^T$ , and  $\omega_t^T$  represent the utility weights. They define how much the variables  $s$  and  $t$  affect the Sender  $S$  and Target  $T$ . The factor  $\omega_s^S \in [0, 1]$  describes how much  $s$  hurts the sender, the factor  $\omega_t^S \in [0, 1]$  describes how much  $t$  hurts the sender, the factor  $\omega_s^T \in [0, 1]$  describes how much  $s$  hurts the target, and the factor  $\omega_t^T \in [0, 1]$  describes how much  $t$  benefits the target. The optimization of the values for  $s$  and  $t$ , in the form of bounded utility maximization, happens with respect to these utility functions.

The adjusted value for sanction  $s_a$  is calculated through the input of the current level of sanction  $s$ , the current level of topic  $t$ , and the expected level of topic  $t_x$  (as calculated in Section 3.2.2.2. *Beliefs* on page 29):

- The value of sanctions  $s$  is *increased* by a certain level  $\Delta_s$ , if the utility  $u^S$  of the increased value is bigger than the utility of the current level. Because the utility function  $u^S$  also depends on the amount of  $t$ , this amount is set by the expected value  $t_x$  for the increased rate.
- The value of sanctions  $s$  is *decreased* by a certain level  $\Delta_s$ , if the utility  $u^S$  of the decreased value is bigger than the utility of the current level. As the utility function  $u^S$  also depends on the amount of  $t$ , this amount is set by the expected value  $t_x$  for the decreased rate.

- In all other cases the adjusted value for sanction  $s_a$  corresponds to the current level of  $s$ .

Algorithm 3.3. illustrates this bounded optimization procedure for sender  $S$ , which also takes into account the expected reaction of the other side. The sender will change sanctions in such a way that its expected utility will increase or at least not decrease.

The adjusted value for topic  $t_a$  is calculated through the input of the current level of sanction  $s$ , the current level of the topic  $t$  and the expected level of sanction  $s_x$  (as calculated in Section 3.2.2.2. *Beliefs* on page 29):

- The value of topic  $t$  is *increased* by a certain level  $\Delta_t$ , if the utility  $u^T$  of the increased value is bigger than the utility of the current level. Because the utility function  $u^T$  also depends on the amount of  $s$ , this amount is set by the expected value  $s_x$  for the increased rate.
- The value of topic  $t$  is *decreased* by a certain level  $\Delta_t$ , if the utility  $u^T$  of the decreased value is bigger than the utility of the current level. Because the utility function  $u^T$  also depends on the amount of  $s$ , this amount is set by the expected value  $s_x$  for the decreased rate.
- In all other cases the adjusted value for the topic  $t_a$  corresponds to the current level  $t$ .

Algorithm 3.4. illustrates this bounded optimization procedure for target  $T$ , which also accounts for the expected reaction of the other side. The target will change the topic in such a way that its expected utility will increase or at least not decrease.

Algorithm 3.3.: Reaction function of sender  $S$ , optimizing the value for sanction  $s$

---

**input** :sanction  $s$ , topic  $t$ , expected topic  $t_x$   
**output**: adjusted sanction  $s_a$   
initialization;  
**if** *Utility of increasing sanction (including the expected reaction of the other side) is bigger than keeping it the same;*  
 $u^S(s + \Delta_s, t_x(s + \Delta_s)) > u^S(s, t_x(s))$   
**then**  
    sanction will be increased;  
     $s_a := s + \Delta_s$ ;  
**else if** *Utility of decreased sanction (including the expected reaction of the other side) is bigger than keeping it the same;*  
 $u^S(s - \Delta_s, t_x(s - \Delta_s)) > u^S(s, t_x(s))$   
**then**  
    sanction will be decreased;  
     $s_a := s - \Delta_s$ ;  
**else**  
    sanction will stay the same;  
     $s_a := s$ ;  
**end**

---

Algorithm 3.4.: Reaction function of target  $T$ , optimizing the value for topic  $t$

---

**input** :sanction  $s$ , topic  $t$ , expected sanction  $s_x$   
**output**: adjusted topic  $t_a$   
initialization;  
**if** *Utility of increasing topic (including the expected reaction of the other side) is bigger than keeping it the same;*  
 $u^T(s_x(t + \Delta_t), t + \Delta_t) > u^T(s_x(t), t)$   
**then**  
    topic will be increased;  
     $t_a := t + \Delta_t$ ;  
**else if** *Utility of decreased topic (including the expected reaction of the other side) is bigger than keeping it the same;*  
 $u^T(s_x(t - \Delta_t), t - \Delta_t) > u^T(s_x(t), t)$   
**then**  
    topic will be decreased;  
     $t_a := t - \Delta_t$ ;  
**else**  
    topic will stay the same;  
     $t_a := t$ ;  
**end**

---

#### 3.2.2.4. Emotions

Emotions can be understood as a positive or negative mindset towards a situation or an actor. In the case of sanctions, emotions can be understood as an additional component in the perception of the other side's behavior, an additional factor in the evaluation of sanction  $s$  and topic  $t$ . In the context of state actors, such a factor could, for example, be of an ideological nature. This factor can lead to a situation in which a certain action from the other side induces the ideologically motivated demand to react in a particular way. It can be understood as an external reward that is obtained by following a set of normative beliefs or ideas.

The presented model defines rules, which represent emotional reactions.



A function is introduced that incorporates opposition toward increased pressure. If the other side increases pressure, the incentive to oppose this pressure grows, and the willingness for concession decreases. This opposing function describes an external reward for resisting pressure. In the context of state actors, this function can be understood as an effect similar to the *rally around the flag syndrome*, where external pressure increases support for the government (Mueller, 1970). This is implemented in the model through rules that control the circumstances under which additional opposition towards the other side will take place. The extent of this type of opposition in turn is defined through the respective opposing functions.

For the sender  $S$ , opposing is activated if the topic  $t$  has increased over the last round. Otherwise, opposing is not effective. Algorithm 3.5. shows this implementation. For the target the  $T$ , opposing is activated if sanction  $s$  has increased over the last round. Otherwise, opposing is not effective. Algorithm 3.6. illustrates this implementation.

Algorithm 3.5.: Opposing of sender  $S$  toward the increased topic  $t$

---

```

input : topic last round  $t_{n-1}$ ,
        topic current round  $t_n$ ,
        opposing factor  $o^S$ 
output:  $opposing^S$ 
initialization;
if topic has been increased;
 $t_n - t_{n-1} > 0$  then
    opposing is effective;
     $opposing^S := o^S \cdot t_n^2$ ;
else
    opposing is not effective;
     $opposing^S := 0$ ;
end

```

---

Algorithm 3.6.: Opposing of target  $T$  toward the increased sanctions  $s$

---

```

input : sanction last round  $s_{n-1}$ ,
        sanction current round  $s_n$ ,
        opposing factor  $o^T$ 
output:  $opposing^S$ 
initialization;
if sanction has been increased;
 $s_n - s_{n-1} > 0$  then
    opposing is effective;
     $opposing^T := o^T \cdot \sqrt{s_n}$ ;
else
    opposing is not effective;
     $opposing^T := 0$ ;
end

```

---

The implementation of opposing in the model happens through the utility optimization function, where opposing is treated as an additional factor of the process that is described in Section 3.2.2.3. *Optimization* on page 31. For the sender  $S$ , opposing, when it is activated, rises the likelihood of an increase in sanction. The sanction  $s$  will be increased if

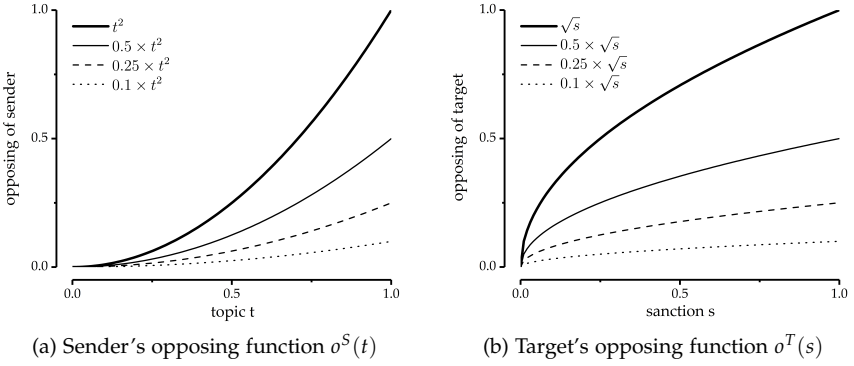
the following statement is true:

$$u^S(s + \Delta_s, t_x(s + \Delta_s)) + \textit{opposing}^S > u^S(s, t_x(s)). \quad (3.5.)$$

For target  $T$  opposing, when it is activated, lowers the likelihood for giving in and decreasing  $t$ . Topic  $t$  will be decreased if the following statement is true:

$$u^T(s_x(t - \Delta_t), t - \Delta_t) - \textit{opposing}^T > u^T(s_x(t), t). \quad (3.6.)$$

The amount of opposition depends on the level of escalation. For the sender  $S$ , the opposing is modeled as a progressive increasing function in dependence of topic  $t$ . It is assumed that an increase in  $t$  increases the opposition. Furthermore, it is assumed that this increase is growing because minor misbehavior is more likely to be tolerated than major misbehavior. Therefore, a quadratic function in the form of  $t^2$  is used to model the opposing function of  $S$ . For the target  $T$ , the opposing is modeled as a degressive increasing function in dependence of sanction  $s$ . It is assumed that an increase in  $s$  increases the opposition. Furthermore, it is assumed that this increase is decreasing because punishment loses its effect. Therefore, a square root function in the form of  $\sqrt{s}$  is used to model the opposing function of  $T$ . These functions are further regulated through a multiplication with the opposing factor  $o^S \in [0, 1]$  for the sender and the opposing factor  $o^T \in [0, 1]$  for the target that damps down the extent of exposing. Figure 3.8. illustrates these functions for the sender and target, representing the difference in opposing behavior of the two parties.

Figure 3.8.: Opposing functions of  $S$  and  $T$ 

### 3.2.2.5. Learning

If beliefs exist about future actions and the interaction proceeds over many rounds, these beliefs have to withstand the test of being right or wrong over time. It would not be credible to maintain beliefs that are proven to be wrong. Therefore, falsified beliefs must be updated in a purposeful way that can be understood as learning over time.

In the presented model, learning is implemented through rules that update the beliefs and expectations. This updating is done if the beliefs and expectations are proven wrong in the course of the interaction. The adjustment of the beliefs happens in a purposeful way so that they become more accurate over time. See Section 3.2.2.2. *Beliefs* on page 29, for the expectations about how the other side will react to a certain level of sanctions or topic. The basic idea of learning is the adjustment of the thresholds  $\tau^T$  and  $\tau^S$  as illustrated in Figure 3.9.

To process the learning of the sender, the changed threshold  $\tau_{n+1}^T$  is calculated through the input of the change in the topic  $\delta_t = t_{n+1} - t_n$ , the current sanction  $s_n$ , and the current threshold  $\tau_n^T$ .

- If there is no change in topic over the last round and  $t$  is at its upper limit, the threshold will increase by  $\frac{\Delta_s}{2}$ .
- If there is no change in topic over the last round and  $t$  is at its lower

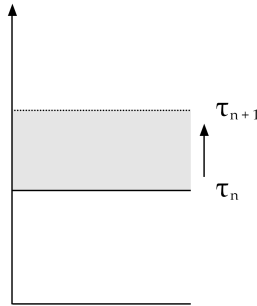


Figure 3.9.: Illustration of the effect of learning, which results in an adjustment of threshold  $\tau$ .

limit, the threshold will decrease by  $\frac{\Delta s}{2}$ .

- If there is no change in topic over the last round and  $s$  is above  $\tau^T$ , the threshold is underestimated and set at  $s + \frac{\sigma^T}{2}$ .
- If there is no change in topic over the last round and  $s$  is below  $\tau^T - \sigma^T$ , the threshold is underestimated and set at  $s + \frac{\sigma^T}{2}$ .
- If there is an increase in topic over the last round and  $s$  is above  $\tau^T - \sigma^T$ , the threshold is underestimated and set at  $s + 1.1 \times \sigma^T$ .
- If there is a decrease in topic over the last round and  $s$  is below or equal to  $\tau^T$ , the threshold is overestimated and decreased to  $s - \Delta s$ .
- Otherwise, the threshold remains the same.

Algorithm 3.7. illustrates this learning procedure of the sender. By implementing these rules, a purposeful adjustment of  $\tau^T$  results. This change happens if the previous value of  $\tau^T$ , the assumption about the point where the other side will change their behavior, can be proven wrong. The adjustment of  $\tau^T$  accounts for newly acquired insights about the nature of the previous error such as underestimation or overestimation.

Algorithm 3.7.: Learning of sender  $S$  (change of threshold  $\tau^T$  after disproof of its accuracy)

---

```

input : change in topic  $\delta_t = t_{n+1} - t_n$ ,
         sanction  $s_n$ ,
         threshold  $\tau_n^T$ 
output: changed threshold  $\tau_{n+1}^T$ 

initialization;
; // boundary conditions
if  $\delta_t = 0$  and  $t$  is at the upper limit then
| threshold will be increased;
|  $\tau_{n+1}^T := \tau_n^T + \frac{\Delta_s}{2}$ ;
else if  $\delta_t = 0$  and  $t$  is at the lower limit
then
| threshold will be decreased;
|  $\tau_{n+1}^T := \tau_n^T - \frac{\Delta_s}{2}$ ;
; // underestimated threshold
else if  $\delta_t = 0$  and  $s > \tau_n^T$  then
| threshold will be increased;
|  $\tau_{n+1}^T := s + \frac{\sigma^T}{2}$ ;
else if  $\delta_t = 0$  and  $s < \tau_n^T - \sigma^T$  then
| threshold will be increased;
|  $\tau_{n+1}^T := s + \frac{\sigma^T}{2}$ ;
else if  $\delta_t > 0$  and  $s \geq \tau_n^T - \sigma^T$  then
| threshold will be increased;
|  $\tau_{n+1}^T := s + 1.1 \times \sigma^T$ ;
; // overestimated threshold
else if  $\delta_t < 0$  and  $s \leq \tau_n^T$  then
| threshold will be increased;
|  $\tau_{n+1}^T := s - \Delta_s$ ;
; // else
else
| threshold will stay the same;
|  $\tau_{n+1}^T := \tau_n^T$ ;
end

```

---

Algorithm 3.8.: Learning of target  $T$  (change of threshold  $\tau^S$  after disproof of its accuracy)

---

```

input : change in sanction
          $\delta_s = s_{n+1} - s_n$ , topic  $t_n$ ,
         threshold  $\tau_n^S$ 
output: changed threshold  $\tau^S$ 

initialization;
; // boundary conditions
if  $\delta_s = 0$  and  $s$  is at the upper limit then
| threshold will be increased;
|  $\tau_{n+1}^S := \tau_n^S + \frac{\Delta_t}{2}$ ;
else if  $\delta_s = 0$  and  $s$  is at the lower limit
then
| threshold will be decreased;
|  $\tau_{n+1}^S := \tau_n^S - \frac{\Delta_t}{2}$ ;
; // underestimated threshold
else if  $\delta_s = 0$  and  $t > \tau_n^S$  then
| threshold will be increased;
|  $\tau_{n+1}^S := t + \frac{\sigma^S}{2}$ ;
else if  $\delta_s = 0$  and  $t < \tau_n^S - \sigma^S$  then
| threshold will be increased;
|  $\tau_{n+1}^S := t + \frac{\sigma^S}{2}$ ;
else if  $\delta_s < 0$  and  $t \geq \tau_n^S - \sigma^S$  then
| threshold will be increased;
|  $\tau_{n+1}^S := t + 1.1 \times \sigma^S$ ;
; // overestimated threshold
else if  $\delta_s > 0$  and  $t \leq \tau_n^S$  then
| threshold will be increased;
|  $\tau_{n+1}^S := t - \Delta_t$ ;
; // else
else
| threshold will stay the same;
|  $\tau_{n+1}^S := \tau_n^S$ ;
end

```

---

To process the learning of the target, the changed threshold  $\tau_{n+1}^S$  is calculated through the input of the change in sanction  $\delta_s = s_{n+1} - s_n$ , the current topic  $t_n$ , and the current threshold  $\tau_n^S$ .

- If there is no change in sanction over the last round and  $s$  is at its upper limit, the threshold will increase by  $\frac{\Delta t}{2}$ .
- If there is no change in sanction over the last round and  $s$  is at its lower limit, the threshold will decrease by  $\frac{\Delta t}{2}$ .
- If there is no change in sanction over the last round and  $t$  is above  $\tau^S$ , the threshold is underestimated and set at  $t + \frac{\sigma^S}{2}$ .
- If there is no change in sanction over the last round and  $t$  is below  $\tau^S - \sigma^S$ , the threshold is underestimated and set at  $t + \frac{\sigma^S}{2}$ .
- If there is an decrease in sanction over the last round and  $t$  is above  $\tau^T - \sigma^T$ , the threshold is underestimated and set at  $T + 1.1 \times \sigma^S$ .
- If there is a increase in sanction over the last round and  $t$  is below or equal to  $\tau^S$ , the threshold is overestimated and decreased to  $t - \Delta t$ .
- Otherwise, the threshold remains the same.

Algorithm 3.8. illustrates this learning procedure of the target. By implementing these rules, a targeted adjustment of  $\tau^S$  results. This happens if the previous value of  $\tau^S$ , the assumption about the point where the other side will change its behavior, can be proven wrong. The adjustment of  $\tau^S$  takes into account newly acquired insights about the nature of the previous error such as underestimation or overestimation.

#### 3.2.2.6. Negotiation

In addition to the previous described interaction, the two players also have the possibility to agree on a negotiated solution. This negotiated outcome describes alternative values for the variables for sanction and topic. These new values of the negotiated sanction  $s_{nego}$  and negotiated topic  $t_{nego}$  are calculated by specific rules, describing a possible negotiated compromise. They are accepted if both sides perceive them to be better than the current situation.

Many possible rules exist that can be applied to generate a negotiated solution for the given problem. The model includes the well-established Nash bargaining solution (NBS) and a straightforward concepts of fixed reductions to generate the negotiation solutions.

### 3.2.2.6.1. Nash Bargaining Solution

The question of finding the two negotiation values  $s_{nego}$  and  $t_{nego}$  can be seen as a classical bargaining problem. A bargaining problem consists of a feasibility set  $N \in \mathbb{R}^2$  (non-empty, convex, and closed), which represents the utilities for each possible contract, and the disagreement point  $d = (d_1, d_2)$ , which represents the utilities of the best alternative to a negotiated agreement for players 1 and 2. A bargaining solution is a function

$$f : (N, d) \mapsto x \in N \quad (3.7.)$$

that selects one of the possible contracts. In this case one specific combination of the values for  $s$  and  $t$ .

Different concepts exist for calculating a bargaining solution. The model implements the well-established NBS that was described by Nash (1950b). He proposed a solution concept that satisfies four axioms. First, invariance to equivalent utility representations means that, if the player's utilities are transformed to different units, then the solution transforms in the same way. Second, Pareto efficiency means that an alternative contract cannot exist that makes any player better off without making at least one player worse off. Third, symmetry means that, if the feasible set of solutions is symmetric, then the solution should lie on a  $45^\circ$  line that emerges from  $d$ . Fourth, independence of irrelevant alternatives means that irrelevant alternatives should not influence the solution. If  $N' \subset N$  contains both  $d$  and  $f(N, d)$ , then  $f(N', d) = f(N, d)$ .

This four axioms define, according to Nash, a reasonable negotiation solution. He proved that the only solution that satisfies these axioms is the point  $(x, y)$ , which maximizes the function

$$(u_1(x) - u_1(d)) \cdot (u_2(y) - u_2(d)) \quad (3.8.)$$

In Function 3.8.,  $u_1$  and  $u_2$  are the utility functions of the two players, and  $d$  is the disagreement point, the outcome obtained if one decides not

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to negotiate. When this function is applied to the discussed model, it is translated to the following maximization problem to find the values for  $s$  and  $t$ , which would then be defined as  $s_{nbs}$  and  $t_{nbs}$ :

$$\max(u^S(s, t) - u^S(d)) \cdot (u^T(s, t) - u^T(d)) \quad (3.9.)$$

To calculate the two values  $s_{nbs}$  and  $t_{nbs}$ , the set of all possible variable combinations and the two disagreement points consisting of the two variables  $s_d$  and  $t_d$  are required. The possible variable combination can be generated if the limits of the variables and their changing values are defined. The disagreement values represent the alternative outcome to a negotiation solution and, therefore, correspond to the level of  $s$  and  $t$ , which are reached without negotiation. These values are defined as the current values for  $s$  and  $t$  in each round. All possible values for sanction  $s_p$  and all possible values for topic  $t_p$  are generated. With these values and the disagreement point, the Nash product for all combinations is calculated. Out of all of the calculated Nash products, the maximum value that is Pareto optimal is selected. From this maximum value, the corresponding values  $s_{nbs}$  and  $t_{nbs}$  are returned. Algorithm 3.9. illustrates this implementation.

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#### Algorithm 3.9.: Calculation of the Nash bargaining solution

---

**input** :disagreement value for sanction  $s_d$ , disagreement value for topic  $t_d$   
**output**:Nash bargaining solution for sanction  $s_{NBS}$ , Nash bargaining solution for topic  $t_{NBS}$

initialization;

**generate** all possible values for sanction  $s$ ;  
 $s_p := [s_{min}, \dots, s_{max}]$ ;

**generate** all possible values for topic  $t$ ;  
 $t_p := [t_{min}, \dots, t_{max}]$ ;

**calculate** the Nash product for all possible combination of  $s$  and  $t$ ;  
 $u^{Nashproduct} := (u^S(s_p, t_p) - u^S(s_d, t_d)) \cdot (u^T(s_p, t_p) - u^T(s_d, t_d))$ ;

**find** maximum in  $u^{Nashproduct}$  that is on the Pareto optimal; **return** corresponding values  $s_{NBS}$  and  $t_{NBS}$ ;

---

The returned values for  $s_{nbs}$  and  $t_{nbs}$  are assessed by the sender and target. They are used as an input to the utility function to calculate the respective utilities. If this bargaining solution leads to a higher utility



than the current combination of sanction and topic, it is perceived as being better and, therefore, is preferred over the present state. If both players prefer the bargaining solution over the status quo, it is accepted and implemented.

### 3.2.2.6.2. Fixed Reduction Negotiation Solutions

In addition to the well established solution concepts for the bargaining problem, there are many other rules which can be utilized to generate a negotiated solution for the given problem. Such a rule should provide a mechanism to calculate the negotiated values for sanctions  $s_{nego}$  and the negotiated value for topic  $t_{nego}$  and at the same time consider the purpose of a negotiation.

A negotiation has the objective to generate an agreement between the two parties. To achieve such a compromise, both sides make some concessions with the intention to achieve a mutual beneficial deal. This mechanism is implemented in the model through a rule, in which both sides reduce their controlled variable by a fixed factor. These are the sanction reduction factor  $s_r \in [0, 1]$  and the topic reduction factor  $t_r \in [0, 1]$ . The proposed negotiated values  $s_{nego}$  and  $t_{nego}$  are therefore a certain percentage of the current value of  $s$  and  $t$ .

In every round, the returned values for  $s_{nego}$  and  $t_{nego}$  are assessed by the sender and target. Therefore, they are used as an input to the utility functions to calculate the respective utilities. If this negotiation solution leads to a higher utility than the current combination of the sanction and topic, it is perceived as better and, therefore, is preferred over the present state. If both players prefer the negotiation solution over the status quo, it is accepted and enforced. Algorithm 3.10. illustrates the implementation of this fixed reduction negotiation solution.

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#### Algorithm 3.10.: Calculation of the fixed reduction negotiation solution

---

**input** : current sanction  $s_n$ , current topic  $t_n$ , sanction reduction factor  $s_r$ , topic reduction factor  $t_r$   
**output**: negotiated sanction  $s_{nego}$ , negotiated topic  $t_{nego}$   
initialization;  
**calculate** the negotiated solution  $s_{nego}$  and  $t_{nego}$ ;  
 $s_{nego} := s_n \cdot s_r$ ;  
**and**  
 $t_{nego} := t_n \cdot t_r$ ;  
**Compare** the negotiated solution to the current amount of sanction and topic;  
**if** negotiation is preferred;  
 $u^S(s_{nego}, t_{nego}) > u^S(s_n, t_n)$  **and**  $u^T(s_{nego}, t_{nego}) > u^T(s_n, t_n)$  **then**  
    solution is accepted;  
     $s_n := s_{nego}$ ;  
     $t_n := t_{nego}$ ;  
**else**  
    solution is rejected;  
**end**

---

### 3.2.3. Simulation Results

This section presents the simulation results of the computational model and discusses the influence of different model parameters. It starts by presenting an overview of the model parameters. It then continues by illustrating the influence of the starting conditions, utility weights, thresholds, opposing, and negotiation on the model. To analyze the influence of these factors, the model is simulated with different values  $[0, 0.25, \dots, 1]$  for the specific variable, while the other factors are kept constant.

#### 3.2.3.1. Considered Variables

The presented model is controlled by a set of variables, which defines the framework conditions of the model and the characteristics of the two players. Therefore, the evaluation of the model has to consider the influences of these variables and their combinations.

General model parameters are the number of rounds  $r$ , which determine how long the two players interact; the lower limit  $l$  and upper limit  $u$ ,

which define the range for the two main variables of sanction  $s$  and topic  $t$ ; the initial values for sanction  $s_0$  and topic  $s_0$ , which define the starting values; and the values of sanction change  $\Delta_s$  and topic change  $\Delta_t$  that define the amount by which the two players can change their controlled variables.

The parameters that describe the characteristics of the two players are the utility functions, beliefs, and opposing. The utility functions are structured by the sender's utility weight of sanctions  $\omega_s^S$ , the sender's utility weight of topic  $\omega_t^S$ , the target's utility weight of sanctions  $\omega_s^T$ , and target's utility weight of topic  $\omega_t^T$ . The beliefs of the players are controlled by the initial value of the sender threshold  $\tau_0^S$  as expected by the target, the initial value of the target threshold  $\tau_0^T$  as expected by the sender, the sender security level  $\sigma^S$  as expected by the target, and the target security level  $\sigma^T$  as expected by the sender. Furthermore, opposing is regulated by the sender's opposing factor  $o^S$  and the target's opposing factor  $o^T$ . Table 3.1. presents an overview of these variables. All of them must be defined for the simulation of the presented model and influence its outcome.

Table 3.1.: Model parameters that must be specified

Domain	Variable	Description	Limitations
General model parameters	$r$	Number of rounds	$[0, \infty)$
	$l$	Lower limit	$l \leq u$
	$u$	Upper limit	$u \geq l$
	$s_0$	Initial sanction value	$[l, u]$
	$t_0$	Initial topic value	$[l, u]$
	$\Delta_s$	Value of sanction change	$[l, u]$
Utility function	$\Delta_t$	Value of topic change	$[l, u]$
	$\omega_s^S$	Sender's utility weight of sanctions	$[0, 1]$
	$\omega_t^S$	Sender's utility weight of topic	$[0, 1]$
	$\omega_s^T$	Target's utility weight of sanctions	$[0, 1]$
Beliefs	$\omega_t^T$	Target's utility weight of topic	$[0, 1]$
	$\tau_0^S$	Initial sender threshold value (expected by target)	$[l, u]$
	$\tau_0^T$	Initial target threshold value (expected by sender)	$[l, u]$
	$\sigma^S$	Security level sender (expected by target)	$[0, \tau_0^S]$
Opposing	$\sigma^T$	Security level target (expected by sender)	$[0, \tau_0^T]$
	$o^S$	Sender's opposing factor	$[0, 1]$
	$o^T$	Target's opposing factor	$[0, 1]$

### 3.2.3.2. Starting Conditions

The initial values of sanction  $s_0$  and topic  $t_0$  determine at which levels the two players start their interaction. This starting condition influences the dynamics and outcome of their interplay. To illustrate this influence, the different interactions for starting condition  $s_0 = \{0, 0.25, \dots, 1\}$  and  $t_0 = \{0, 0.25, \dots, 1\}$  are simulated. Figure 3.10. presents this for  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$  and  $\tau_0^S = \tau_0^T = 0.25$ .

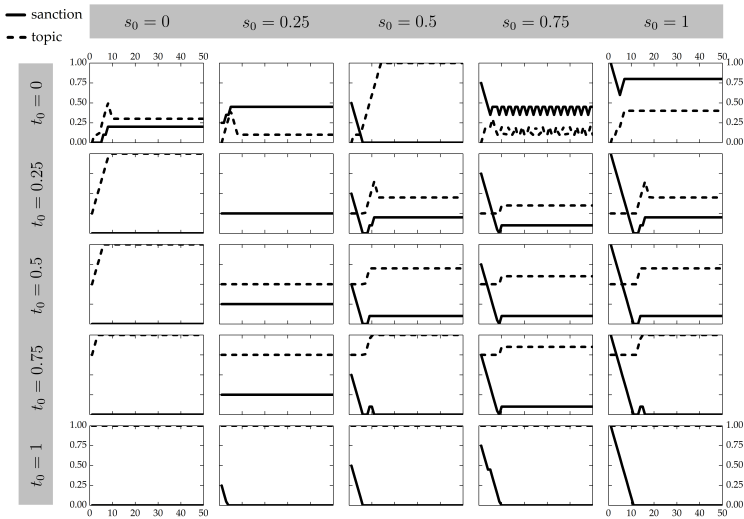


Figure 3.10.: Influence of the different starting conditions  $s_0$  and  $t_0$  in case of utility weights  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$  and  $\tau_0^S = \tau_0^T = 0.25$ .

The results show that, if sanction  $s$  starts at the minimum ( $s_0 = 0$ ), topic  $t$  will increase whenever possible. In the case where the topic also starts at the minimum ( $t_0 = 0$ ), the two variables go up but then remain at a certain level. In all the other cases in which  $t_0$  is bigger, the sanction stays at the minimum, and the topic goes up to the maximum. If the topic starts at the minimum ( $t_0 = 0$ ), the outcome depends on the starting value of the sanction. In many cases in which  $s_0 > t_0$ , it is possible to limit the

topic, with both variables staying at an intermediate value. If the sanction starts at the maximum ( $s_0 = 1$ ), the outcome depends on the starting value of the topic. The sanction decreases, and if  $t_0$  is relatively low, its increase is limited and stays at an intermediate value. If  $t_0$  is relatively high, the topic goes up to the maximum, and the sanction goes down to the minimum. If the topic starts at the maximum ( $t_0 = 1$ ),  $t$  stays at the maximum, and the sanction decreases to the minimum. The intermediate situations are steered by different influencing dynamics. In many cases, the two variables limit each other and stay at an intermediate value.

### 3.2.3.3. Utility Weights

The utility functions describe the cost or benefit of both sanction  $s$  and topic  $t$  to the players and directly influence their interaction. The presented model assumes linear utility functions with utility weights  $\omega_s^S$ ,  $\omega_t^S$ ,  $\omega_s^T$ , and  $\omega_t^T$ .<sup>3</sup> To test their influence, the interaction of the sanctioner and sanctionee with different utility weights is simulated. For comparison reasons, the other parameters are locked: starting values  $s_0$  and  $t_0$  are set to zero, thresholds  $\tau_0^S$  and  $\tau_0^T$  are set to 0.25, and opposing is switched off with  $o^S$  and  $o^T$  set to zero.

When looking at the sender, it is possible to study the interaction of  $\omega_s^S$  and  $\omega_t^S$ , which describes the costs of sanctions and topic to the sender. If the sanction costs are low for the sender, sanctions are implemented and go up to the maximum. If they are more costly, their use is limited. Alternatively, if topic  $t$  is not of importance to the sender, sanctions are not implemented and stay at the minimum. If topic  $t$  is important (costly) for the sender, sanctions are implemented, and the value of the variable  $s$  increases. Figure 3.11. illustrates these opposed tendencies and shows that a combination leads to a stable intermediate amount of sanctions to limit the topic.

When looking at the target, the interaction of  $\omega_s^T$  and  $\omega_t^T$  is of particular interest. This interaction describes the interplay of the cost of sanction  $s$  (how much they hurt) and the benefit of topic  $t$  to the target. If the cost of sanctions for the target is low, topic  $t$  is increased and goes up to

<sup>3</sup>It could be argued that non linear utility functions would better represent the situation of a sanctioner and a sanctionee. However, for clarity reasons, the utilities are limited to linear functions, even though other forms of utility representations could easily be implemented.

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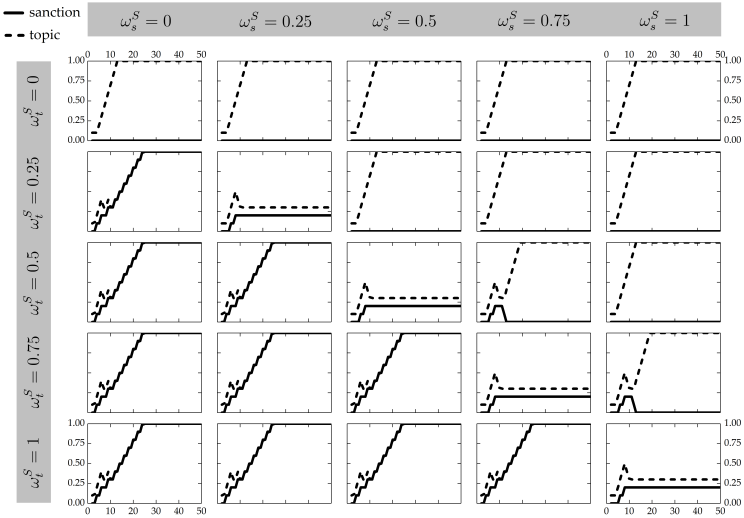


Figure 3.11.: Influence of the sender's utility weights for sanction  $\omega_s^S$  and topic  $\omega_t^S$  if  $\omega_s^T = \omega_t^T = 1$  and  $\tau_0^S = \tau_0^T = 0.25$ .

the maximum. However, if sanctions hurt more, topic  $t$  is not, or only slightly, increased by the target, and an increase in the sanction limits or suppresses the topic variable. Alternatively, if topic  $t$  is of less importance (lower benefit) to the target, it is not increased. If topic  $t$  is of higher importance (bigger benefit), it is increased to the maximum value. The combination of these contrasting tendencies leads to a stable intermediate amount of the topic variable. Figure 3.12. illustrates this concept.

Furthermore, other combinations of the utility weights  $\omega_s^S$ ,  $\omega_t^S$ ,  $\omega_s^T$ , and  $\omega_t^T$  can be studied to see how the different costs and benefits of the sender and target influence their interaction. Figure 3.13. illustrates these outcomes.

The interplay of  $\omega_s^S$  and  $\omega_s^T$  shows how the different costs of sanction  $s$  to the sender and the target influence their interaction. If a sanction is too costly for the sender or does not hurt the target, it is almost never used. Only in cases where the cost of a sanction for the target is at the maximum, the sender uses it to react on an increase of the topic variable.

The interplay of  $\omega_t^S$  and  $\omega_s^T$  shows the linkage between the benefit of topic  $t$  for the sender and the cost of sanction  $s$  for the sender. Here, a clear interaction is not seen, but it becomes evident that, in most combinations of the two utility weights, topic  $t$  increases to the maximum, and sanction stays at the minimum.

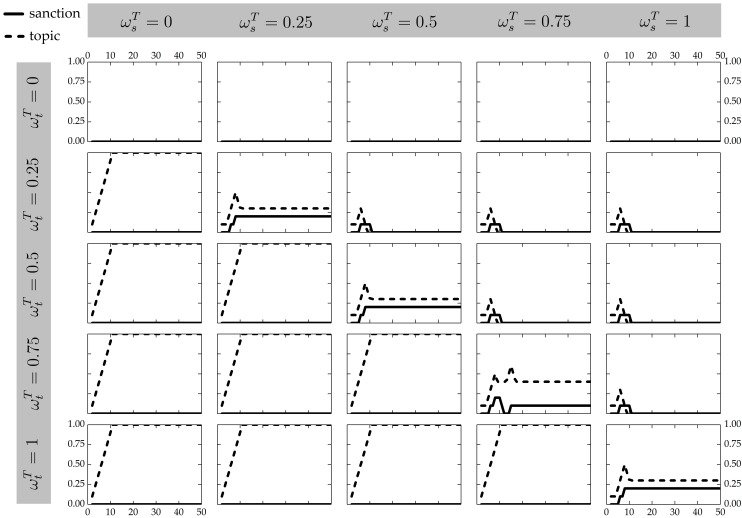


Figure 3.12.: Influence of the target's utility weights for sanction  $\omega_s^T$  and topic  $\omega_t^T$  if  $\omega_s^S = \omega_t^S = 1$  and  $\tau_0^S = \tau_0^T = 0.25$ .

The other combination of  $\omega_s^S$  and  $\omega_t^T$  shows the linkage between the cost of sanction  $s$  (how much it hurts) for the target and the cost of topic  $t$  (how much it hurts) for the target. In most of these combinations, sanctions suppress the emergence of the topic variable on a relatively low level, leading to a situation in which both variables stay at the minimum.

Finally, looking at the interplay of  $\omega_t^S$  and  $\omega_t^T$  shows how the costs of topic  $t$  to the sender and benefits of topic  $t$  to the target influences the interaction. If topic  $t$  is of low benefit for the target, it is not increased and stays at the minimum. If topic  $t$  is of high importance for the sender, sanctions are used to suppress the emergence of the topic.

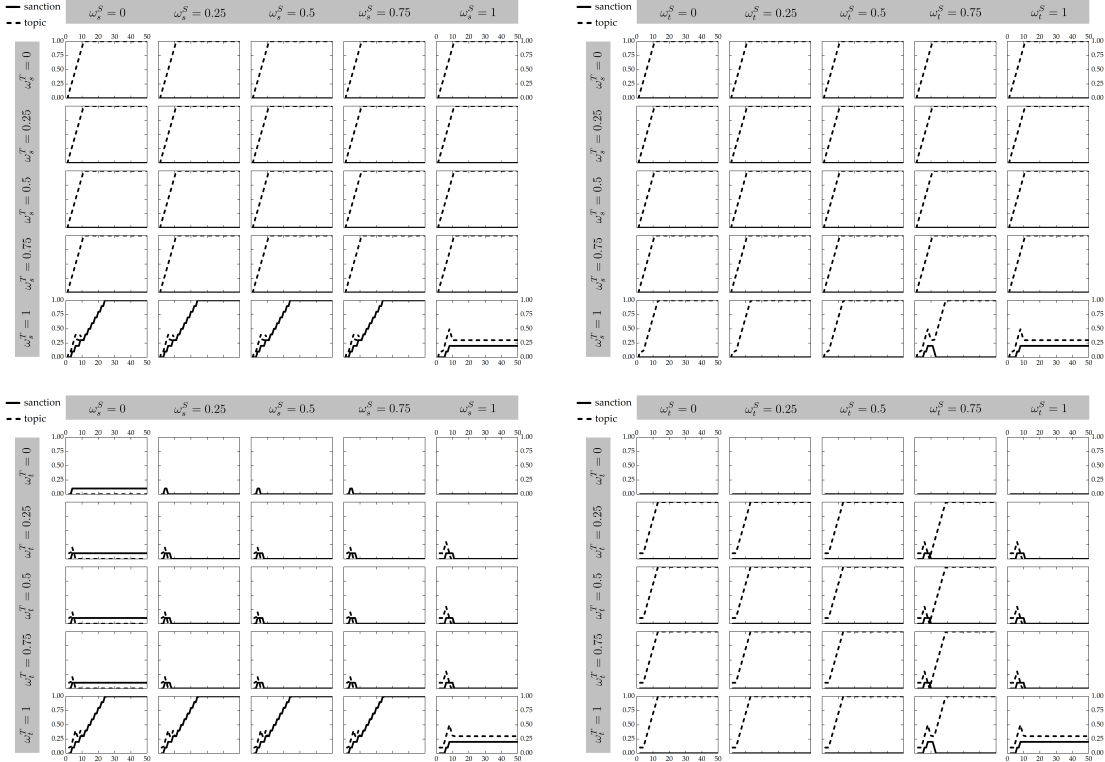


Figure 3.13.: Influence of different combinations of utility weights  $\omega_s^S$ ,  $\omega_t^S$ ,  $\omega_s^T$ , and  $\omega_t^T$  on the interaction of the sender and target, if the other utility weights are set to one and  $\tau_0^S = \tau_0^T = 0.25$ .



### 3.2.3.4. Belief Thresholds

The thresholds  $\tau^S$  and  $\tau^T$  are important elements that define the beliefs how the other side will react. Threshold  $\tau^S$  corresponds to the amount of  $t$ , which the target thinks that will trigger the sender to increase the sanctions. Threshold  $\tau^T$  corresponds to the amount of  $s$  above which the sender thinks that the target will react to the sanctions and decrease the topic. These beliefs influence the behavior of the two players. To illustrate this, Figure 3.14. shows the same interaction as Figure 3.10., but it also shows the levels of thresholds  $\tau^S$  and  $\tau^T$ .

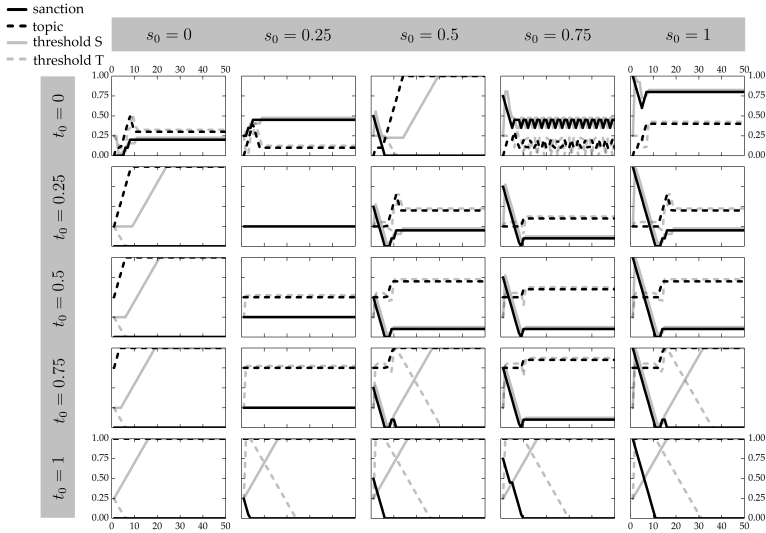


Figure 3.14.: Influence of the thresholds  $\tau^S$  and  $\tau^T$ , where  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$  and  $\tau_0^S = \tau_0^T = 0.25$ .

The thresholds change over time, as learning takes place (as described in Section 3.2.2.5. *Learning* on page 37). Also, the amount of sanction  $s$  or topic  $t$  is often oriented toward the corresponding threshold. For the target, this can be interpreted as staying below the threshold  $\tau^S$ , because the beliefs in this case are that the sender will not react with an increase of sanctions. The sender only slightly increases the sanction  $s$  above  $\tau^T$

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because the sanctions are costly and a decrease in the topic  $t$  is anticipated if the sanctions are just above the threshold.

Furthermore, the initial threshold values  $\tau_0^S$  and  $\tau_0^T$  influence the interaction of the two players. Figure 3.15. illustrates this for the case in which all other values are kept the same.

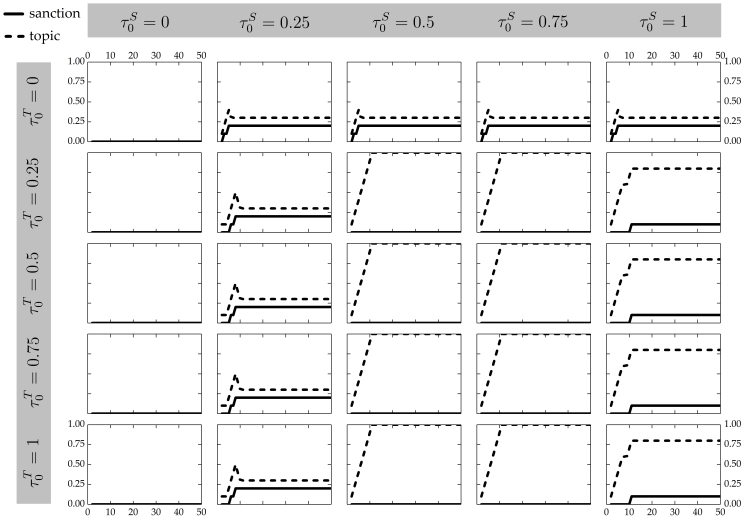


Figure 3.15.: Influence of the different initial threshold values  $\tau_0^S$  and  $\tau_0^T$ , where  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$  and  $\tau_0^S = \tau_0^T = 0.25$ .

A low value for  $\tau_0^S$ , meaning that the target expects the sender to start sanctions already at a low amount of the topic variable, leads to a lower increase in topic  $t$  and sanction  $s$ . The influence of  $\tau_0^T$  is not so clear. It represents the amount of sanction  $s$  that the sender thinks is necessary to bring the target to give in. If this value is low, an increase in sanctions is more likely, and an increase in the topic variable is suppressed.

#### 3.2.3.5. Opposing Factors

Opposing is an important element that reflects an emotional dimension and influences the decisions of the sender and target. The opposing

element is implemented through opposing functions, which are regulated through the opposing factors  $o^S$  and  $o^T$ . For the sender, opposing leads to increased probability of escalation, if the other side increased the topic in the last round. For the target, opposing leads to less willingness for reducing the topic, if the other side increased sanctions in the last round.

To test the influence of opposing, the model was simulated for different values of  $o^S$  and  $o^T$ , where all the other parameters were kept the same. Figure 3.16. illustrates this simulation for  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$ . In this case, an increase in  $o^S$  (the probability of the sender to increase sanctions if the topic was increased in the last round) above a certain value leads to an escalation of  $s$  and  $t$  with a later decrease in  $s$  toward zero. On the other hand,  $o^T$ , which reduces the willingness for the target to give in, does not directly influence the outcome of the interaction.

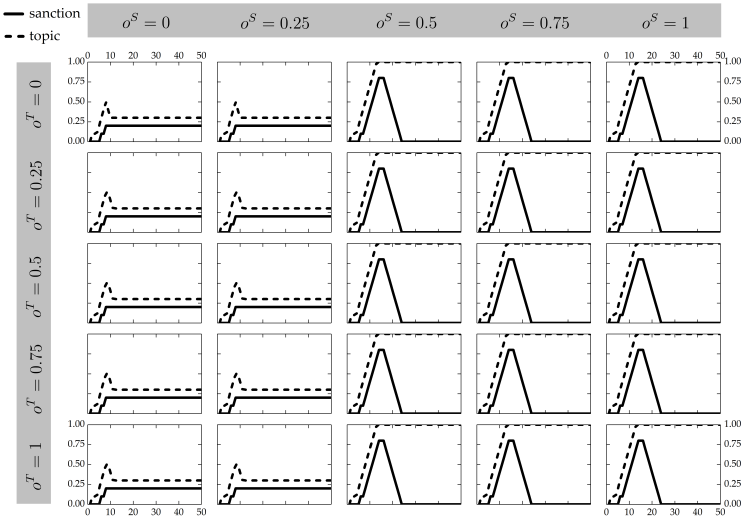


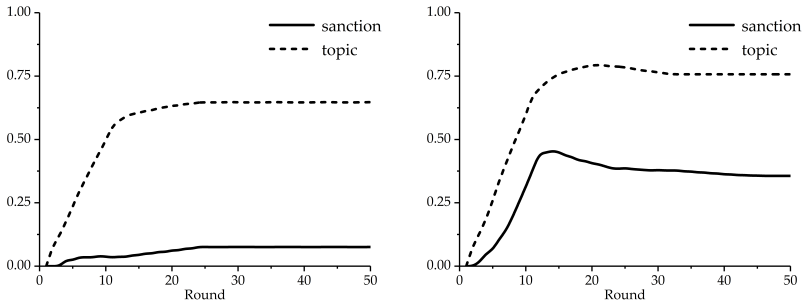
Figure 3.16.: Influence of the opposing values  $o^S$  and  $o^T$  where  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$ .

To see a more general influence of opposing on the interaction, a simulation of all 625 combinations of the values  $\{0, 0.25, \dots, 1\}$  for  $\omega_s^S$ ,  $\omega_t^S$ ,  $\omega_s^T$ , and  $\omega_t^T$  was conducted. These combinations are simulated once

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with  $o^S = o^T = 0$  (no opposing) and once with  $o^S = o^T = 0.25$  (slight opposing). Figure 3.17. illustrates the results.



(a) Meanvalues for simulations with  $o^S = o^T = 0$  (b) Meanvalues for simulations with  $o^S = o^T = 0.25$

Figure 3.17.: Mean values of sanction  $s$  and topic  $t$  for the simulation of 625 combinations of  $\omega_s^S$ ,  $\omega_t^S$ ,  $\omega_s^T$ , and  $\omega_t^T$

These simulations are aggregated through the calculation of the mean value of sanction  $s$  and topic  $t$  for each round. In the case with no opposing, the mean value for sanctions only slowly decreases and stays at a low level, where the mean value for the topic variable increases and remains at a relatively high level. In the case with opposing, the mean value for sanction  $s$  shows a stronger increase and remains at an intermediate level, where the mean value for topic  $t$  shows a similar course as before with a slightly higher end state.

### 3.2.3.6. Negotiation Results

#### 3.2.3.6.1. Nash Bargaining Solution

The Nash bargaining solution can be used to determine a possible negotiation solution  $(s_{NBS}, t_{NBS})$ . This negotiation solution has to be Pareto optimal. For the defined conflict structure, this condition can only be achieved if  $s_{NBS} = 0$ , as all  $s_{NBS} > 0$  lead to a reduction in the utility of both Sender and Target. The value for  $t_{NBS}$  is calculated through the maximization of the Nash product, which can, in the case of linear utility functions, be formulated as

$$\max_{t \in [0,1], s=0} ((-\omega_s^S s - \omega_t^S t) - (-\omega_s^S s_d - \omega_t^S t_d)) \cdot ((-\omega_s^T s + \omega_t^T t) - (-\omega_s^T s_d + \omega_t^T t_d)) \quad (3.10.)$$

Its outcome depends on the definition of the utility functions and therefore on the utility weights  $\omega_s^S$ ,  $\omega_t^S$ ,  $\omega_s^T$ , and  $\omega_t^T$  as well as on the disagreement values  $s_d$  and  $t_d$ . The disagreement values are defined in the model as the levels of  $s$  and  $t$  at the current round of the simulation. It is therefore essential to study the negotiation solution  $(s_{NBS}$  and  $t_{NBS})$  in condition to  $s_d$  and  $t_d$ .

If all the utility weights are set equal to one ( $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$ ), one obtains a bargaining solution  $s_{NBS} = 0$  and a bargaining solution  $t_{NBS}$ , which only depends on  $t_d$ . The amount for a negotiated sanction value is independent of the current value of topic  $t$  and it only depends on the current value of sanction  $s$ . The negotiated solution would therefore be  $(s_{NBS} = 0, t_{NBS} = t_d)$ . This is illustrated in Figure 3.18., where the utility-space for all possible utility combinations and the dependence of  $t_{NBS}$  from  $t_d$  and  $t_d$  is represented.

If different values for the utility weights are assumed, the utility-space as well as the Nash bargaining solution change. If sanctions are not as costly for the sender,  $\omega_s^S$  is reduced and if the topic is of less importance for the sender,  $\omega_t^S$  is reduced. If on the other hand sanctions do not harm the target so much,  $\omega_s^T$  is reduced and if the topic is not of high importance to the target,  $\omega_t^T$  is reduced. The influence of these different scenarios on the utility-space and on the Nash bargaining solution  $t_{NBS}$  is illustrated in Figure 3.19. In all this scenarios  $s_{NBS}$  is zero.

### 3. Formal Models

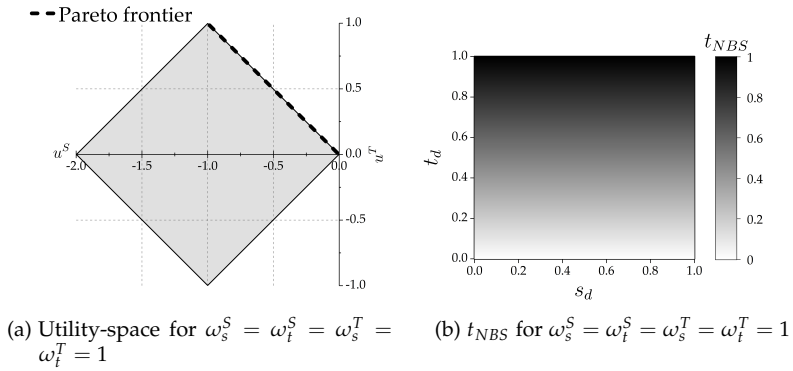


Figure 3.18.: Illustration of the utility-space and the Nash bargaining solution value  $t_{NBS}$  for utility weights  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$

The usefulness of the Nash bargaining solution for the presented conflict structure is limited. Leading always to a complete reduction in sanction is a strong concession by the sender, which does not always seem to be realistic. Therefore, the Nash bargaining solution can only represent some aspects of a reasonable negotiated agreement.

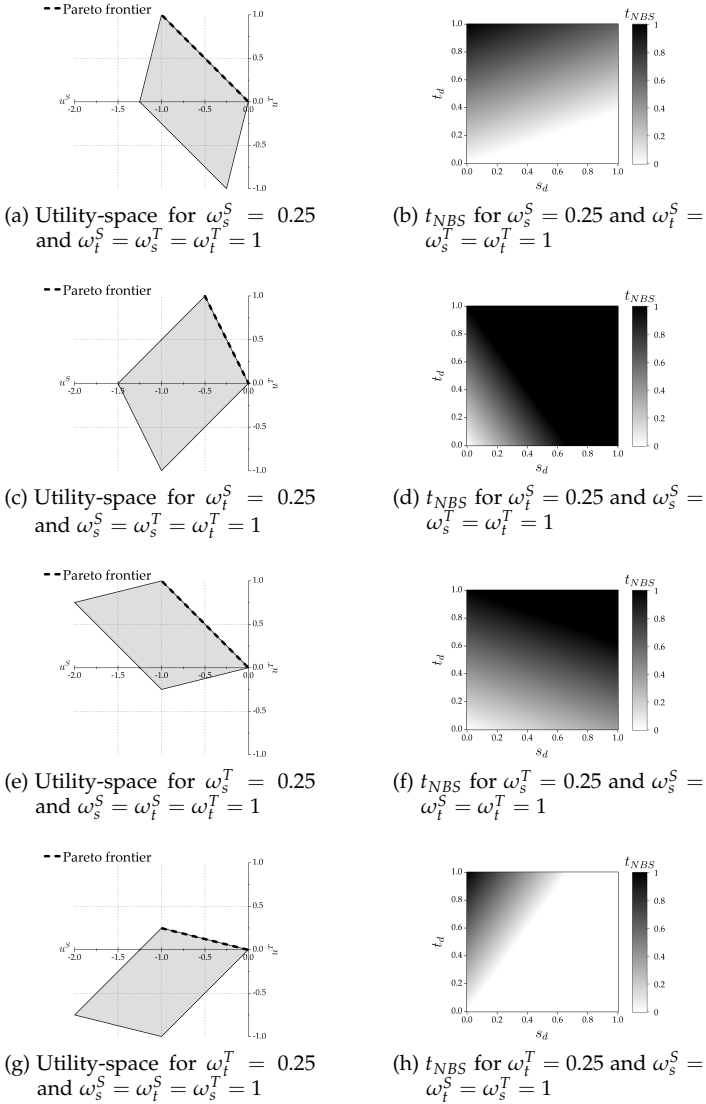


Figure 3.19.: Illustration of the utility-space and the Nash bargaining solution value  $t_{NBS}$  for different utility weights  $\omega_s^S, \omega_t^S, \omega_s^T,$  and  $\omega_t^T$

### 3.2.3.6.2. Fixed Reduction Negotiation Solutions

The fixed reduction negotiation solution is a simplified concept to calculate the values for an agreement. Nevertheless, it can provide some additional insights into the occurrence and acceptance of a negotiated solution.

Considering the case of simple linear utilities, the analysis shows that the sender  $S$  would always agree to a fixed reduction independent of the amount of reduction of  $s$  and  $t$ . This is due to the fact that every reduction increases its utility.

The target  $T$ , on the other hand, would never agree to a deal in which sanctions would not be reduced. If, however  $s$ , is to be reduced, the acceptance of a negotiated solution not only depends on its own reduction but also on the current amount of  $s$  and  $t$ . Figure 3.20. illustrates this relation for different reduction factors  $s_r$  and  $t_r$ .

For  $\omega_s^S = \omega_t^S = \omega_s^T = \omega_t^T = 1$ , the target always accepts a negotiated solution when there is no reduction in topic ( $t_r = 1$ ). In the other cases, the acceptance also depends on the current amount  $s$  and  $t$ .

This shows that even though, the negotiation solution is calculated for every round, it is often not accepted. Only when the negotiation solution is better for both players, can it be accepted. There are many cases in which this does not apply, and a negotiated solution would not have a chance of being accepted. However, in other situations, the players would accept the calculated values  $s_{nego}$  and  $t_{nego}$ .

Figure 3.21. illustrates two cases in which a negotiation solution would become more attractive. It visualizes the development of sanction  $s$  and topic  $s$  if the first acceptable negotiation solution would be agreed on. The first example represents a case in which the acceptance of a negotiation solution becomes possible early on and the two parties manage to remain at a relatively low level of confrontation. If they do not agree on the negotiated solution, an escalation occurs. The second example shows a case in which escalation occurs and a negotiation solution becomes possible on a relatively high level of confrontation. If they do not agree on the negotiated solution, both variables decrease over time.

These two examples demonstrate that there are cases in which a negotiated solution becomes possible with ongoing escalation. They also illustrate that the acceptance of a negotiated solution can be beneficial and prevent further escalation. However, under some conditions, the accep-



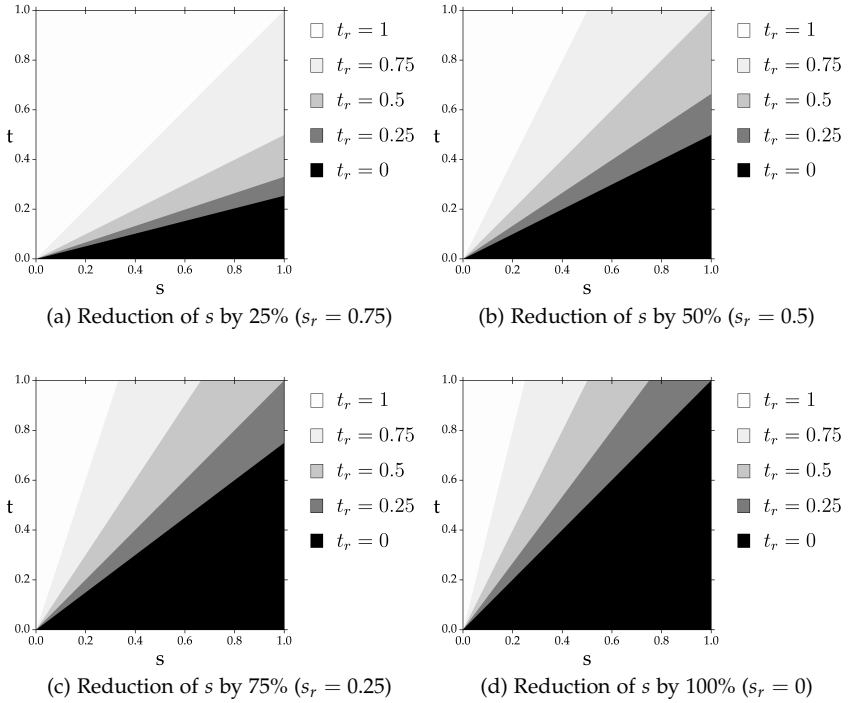
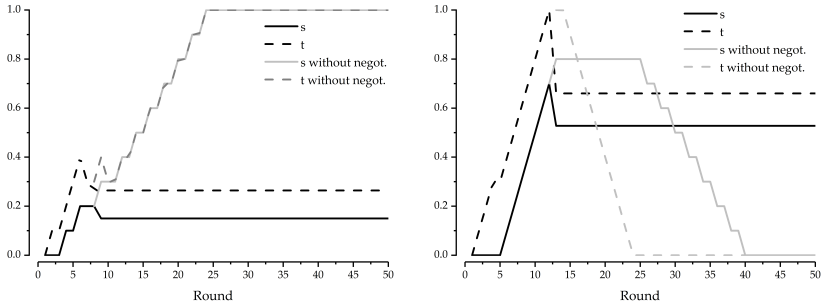


Figure 3.20.: Zone of acceptance of the negotiation solution by the target for utility weights  $\omega_s^S = \omega_f^S = \omega_s^T = \omega_f^T = 1$  (the respective zone includes all darker areas)

tance of a negotiated solution can also affirm a confrontational situation and prevent a clear victory by one side.

### 3. Formal Models



- (a) Interaction development for the parameters:  $s_0 = t_0 = 0$ ,  $\tau_0^S = \tau_0^T = 0.25$ ,  $\omega_s^S = 0.75$ ,  $\omega_t^S = \omega_s^T = \omega_t^T = 1$ ,  $o_S = o_T = 0$ ,  $s_r = 0.5$ ,  $t_r = 0.66$ .
- (b) Interaction development for the parameters:  $s_0 = t_0 = 0$ ,  $\tau_0^S = \tau_0^T = 0.5$ ,  $\omega_s^S = 0.25$ ,  $\omega_t^S = \omega_s^T = \omega_t^T = 1$ ,  $\omega_t^T = 0.75$ ,  $o_S = o_T = 0.25$ ,  $s_r = t_r = 0.66$ .

Figure 3.21.: Examples in which the first negotiation solution that is better for both players (compared to the current state) is accepted.

#### 3.2.3.7. Important Patterns

Simulating the model leads to the emergence of typical patterns of how the two players interact. Figure 3.22. illustrates four of these patterns, which are discussed in this section. First, there are cases that show a stable outcome with no sanctions and no implemented topic variable. Second, there are situations where the topic  $t$  increases to the maximum and sanction  $s$  stays at the minimum. Third, there are situations that lead to a stable intermediate outcome. Fourth, there are cases in which a two-sided escalation occurs.

In cases that lead to a stable outcome, both the topic variable and the sanction variable are zero, as illustrated in Figure 3.22a. Such behavior can emerge, for example, if the target is more hurt by the sanctions than benefits from the topic ( $\omega_s^T \gg \omega_t^T$ ). In this case, only a slight temporary increase in  $s$  and  $t$  occurs with a stable equilibrium of zero sanctions and zero manifestation of the topic variable. Furthermore, cases in which there are no increases in topic  $t$  and sanction  $s$  are observed if the threshold  $\tau_0^S$  is low. In such a situations, the target believes that already a small

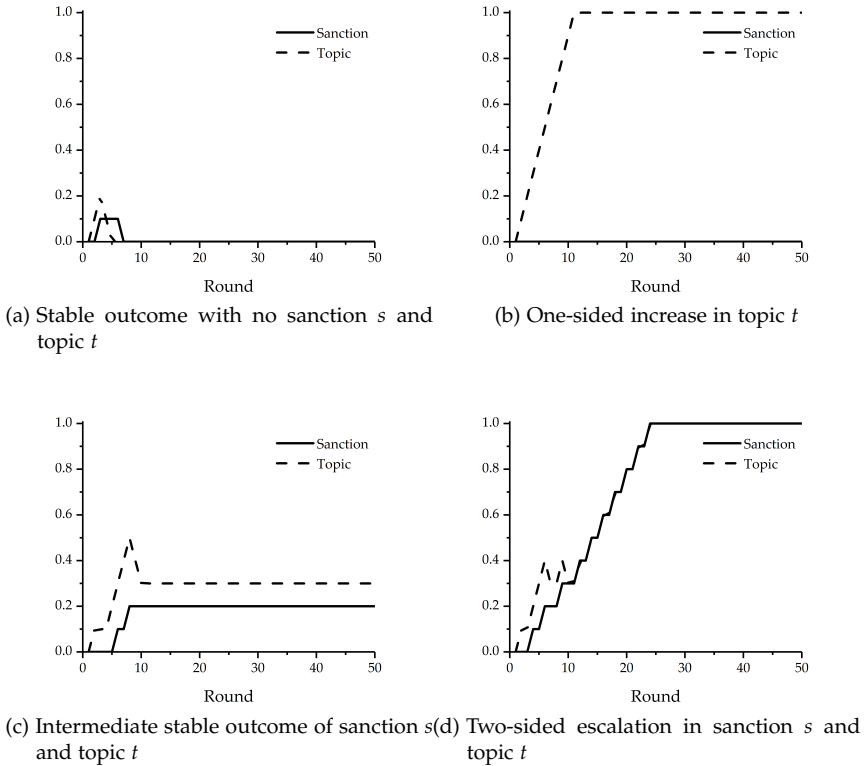


Figure 3.22.: Important patterns that occur in the model

increase in topic  $t$  would trigger sanctions as a reaction. The consequences of such a belief result in that both players retaining their variables at zero.

In other cases, the topic increases to the maximum, where the sanctions are not issued. Figure 3.22b. illustrates such a pattern. This dynamic that can often be observed in the model, for example, in cases where  $\tau_0^S$  and  $\tau_0^T$  are relatively high. In such situations, the target believes that it can increase topic  $t$  at least up to a certain point, and the sender thinks that it

needs a high value of sanction  $s$  (which is costly) to bring the other side to capitulate. In addition, many cases that lead to such patterns are caused by different utility weights. For example, this occurs when the topic is not of high importance for the sender, or the sanctions are costly. In addition, a topic of high importance for the target and for which relatively low costs are imposed by the sanctions can lead to such an outcome.

In some cases, the sanction  $s$  and topic  $t$  will remain stable at an intermediate level, as illustrated in Figure 3.22c. This kind of pattern can be seen with regard to intermediate values of the variables and mixed influences of the different mechanisms. Both sides increase their variables by a certain amount, before stopping due to increased costs.

A typical pattern is the two-sided escalation of the sanction  $s$  and topic  $t$ , as illustrated in Figure 3.22d. This two-sided increase can happen if, for example, an increase in topic hurts the sender more than an equal increase in sanction. Alternatively, increased opposing can lead to such an escalation.

No situations were detected in which the sanction  $s$  increases without an increase of the topic  $t$ . This is because such behavior only leads to additional costs for both sides, without any benefit.

## 3.3. Graph Model

### 3.3.1. General Remarks

Important literature is available on analytical models to study interactions among players and, in particular, conflict situations. A large part of these models rely on game theory, providing insights regarding the strategic interaction and decision-making. One difficulty with such models is often that they are too simplified for representation of a real-world case or they otherwise become too complex to remain analytically solvable.

This section introduces a particular approach that is based on a game-theoretical philosophy, which tries to overcome these difficulties. Relying on a representation in graph form, this established methodology (Hipel et al., 2010) allows use of an analytical, equilibrium-oriented perspective on conflicts while providing the flexibility to apply it to more complicated situations.

### 3.3.2. Graph Model for Conflict Resolution

The Graph Model for Conflict Resolution (GMCR) is an established tool to strategically analyze the interaction of moves and countermoves of decision makers (DMs) in a conflict situation as they attempt to do as well as possible. Its theory and methodology are based on the description of such moves by using directed graphs (Fang, Hipel, & Kilgour, 1989, 1993; Xu, Hipel, Kilgour, & Fang, 2018).

The GMCR approach consists of a modeling and analysis step. In the first step, the main properties of the conflict are identified. These are the DMs, options under the control of each DM, feasible states that consist of option combinations across DMs, possible transitions between states that are encapsulated by a directed graph for each DM, and relative preferences of these states for each DM. In the second step, the model is analyzed for different types of solution concepts that are mathematically defined possible human behaviors under conflict. These concepts reflect the outcome of the interaction among the DMs. A state which is stable for all of the DMs in the conflict, according to a specific type of solution concept, persists as a possible resolution or equilibrium because there is no incentive for any DM to move away from it. The GMCR methodology uses a rich range of stability definitions that describe possible human

interactions in a conflict situation based on factors such as risk, foresight, and available information. The solution concepts that are used within the GMCR methodology at the analysis stage include:

- Nash stability, where a DM cannot unilaterally move to a more preferred state (von Neumann & Morgenstern, 1944; Nash, 1950a, 1951);
- General Metarationality (GMR), in which all unilateral improvements of a DM are sanctioned (changed to a less preferred state) by subsequent unilateral moves by others (Howard, 1971);
- Sequential stability (SEQ), where all unilateral improvements of a DM are sanctioned (changed to a less preferred state) by subsequent unilateral improvements by others (Fraser & Hipel, 1979, 1984);
- Symmetric Metarationality (SMR), in which all unilateral improvements are still changed to a disadvantageous state, even after two steps of response and counter-response (Howard, 1971).;
- Limited-move stability ( $L_h$ ), where all unilateral improvements, following a fixed number of responses and counter-responses ( $h$ ), will not benefit the DM (Kilgour, 1985); and
- Non-myopic stability (NM), where all unilateral improvements, following an unlimited sequence of responses and counter-responses, will not benefit the DM (Kilgour, 1984; Fang et al., 1993).

These methods try to reflect different kinds of human behavior that are present in strategic interactions when dealing with risk and foresight. Table 3.2 presents a comparison of the solution concepts. For example, in this table, the Nash stability, GMR, and SMR do not require a knowledge of the preferences of the other DMs who are participating in a conflict when carrying out a stability analysis of a particular state from a focal DM's viewpoint. The focal DM is only worried about whether he or she might end up in a worse position when taking advantage of a unilateral improvement, not whether sanctions harm the sanctioning DMs. Additionally, when the preferences of the sanctioning DMs are not known, Nash stability, GMR, and SMR can still be used in a stability analysis. The combined results of these analyses can be used to characterize the stability

of potential conflict outcomes. If a state is stable for all of the DMs in a conflict according to a given solution concept, the state constitutes an equilibrium with respect to that solution concept.

The application of the GMCR, including model calibration, stability calculation, and the interpretation of results, can be assisted by the decision support systems GMCR II (Hipel, Marc Kilgour, Fang, & Peng, 1997; Fang, Hipel, Kilgour, & Peng, 2003a, 2003b) and GMCR+ (Kinsara, Petersons, Hipel, & Kilgour, 2015). These systems provide an easy-to-use interface for the underlying evaluation. An application and exemplification of the GMCR method on the Iran nuclear dispute is described in Section 4.3 *Graph Model* on page 99.

Table 3.2.: Comparison of stability concepts for describing strategic behavior, based on (Hipel, 2011)

Stability concept	Stability description	Disimprovement	Foresight	Knowledge of preferences	Strategic risk
Nash	DM cannot unilaterally move to a more preferred state.	Never	Low	Own	Ignores risk
GMR	All focal DM's unilateral improvements are sanctioned by subsequent unilateral moves by others.	By opponents	Medium	Own	Avoids risk
SEQ	All focal DM's unilateral improvements are sanctioned by subsequent unilateral improvements by others.	Never	Medium	All	Takes some risk
SMR	All focal DM's unilateral improvements are still sanctioned even after a possible response by the original DM.	By opponents	Medium	Own	Avoids risk
$L_h$	All DMs are assumed to act rationally within a fixed number of state transitions ( $h$ ).	Strategic	Variable	All	Accepts risk
NM	Limiting case of limited move stability as the maximum number of state transitions increases to infinity.	Strategic	High	All	Accepts risk



# 4. Iran Nuclear Dispute

## 4.1. Case Analysis

### 4.1.1. Background

With around 81 million inhabitants, the Islamic Republic of Iran is the most populated country in the Middle East (United Nations, 2017). It is bordered by Armenia and the Republic of Azerbaijan in the northwest, by Turkmenistan in the northeast, by Afghanistan and Pakistan in the east and by Turkey and Iraq in the west. It is furthermore strategically located between two of the world's largest reservoirs of oil and natural gas, the Caspian Sea in the north and the Persian Gulf and Gulf of Oman in the south. Iran possesses the second largest proven natural gas reserves (Central Intelligence Agency, 2017a) and the fourth largest proven oil reserves (Central Intelligence Agency, 2017b) in the world. Figure 4.1. illustrates the location of Iran and its neighboring countries.

Iran's modern history is tumultuous and complex. During the Second World War, in 1941, an Anglo-Soviet invasion of Iran forced the Shah Reza Pahlavi to abdicate after almost 16 years of ruling. During this time, he introduced many socio-economic reforms and established an authoritarian government that was built on nationalism, secularism, and militarism with strict censorship and state propaganda (Cronin, 2003). After his abdication, he was replaced by his son Mohammad Reza Pahlavi, who held good relationships with Western countries. Initially, the new Shah gave a lot of power to the parliament, which became chronically unstable, leading to six different prime ministers between 1947 and 1951.

In 1951, Mohammad Mosaddegh was appointed as prime minister after being elected by the parliament. His new administration introduced a wide range of social and political reforms (Gasiorowski, 2004). It also further nationalized the British-owned Anglo-Iranian Oil Company, which controlled the Iranian oil industry. These actions led to a disturbance of relations with Western allies. In 1953, a successful coup d'état, which

#### 4. Iran Nuclear Dispute

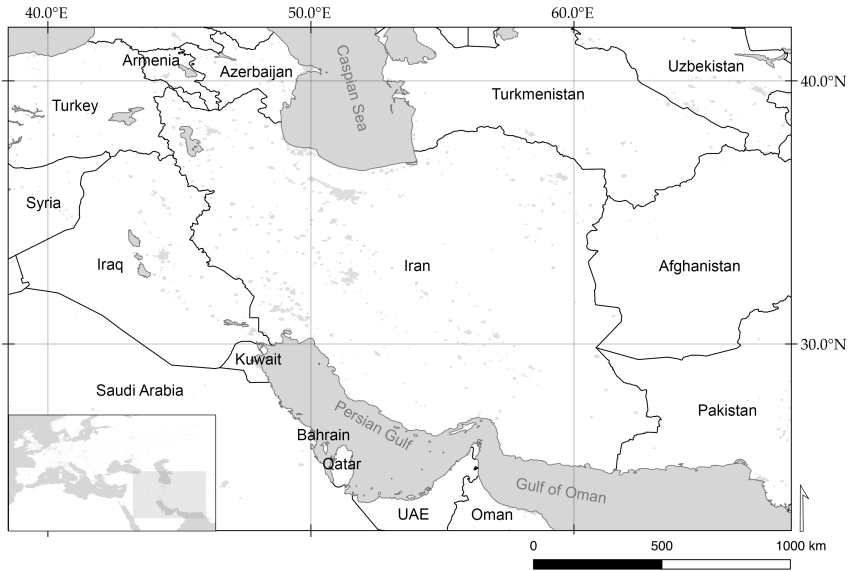


Figure 4.1.: Map of Iran and its neighboring countries

was organized by the American Central Intelligence Agency (CIA) with support of the British MI6, forced Mosaddegh from office, resulting in a substantial interruption of the Iranian political development. From that time onward, the Shah ruled Iran as an autocracy that was supported by the US.

Mohammad Reza Pahlavi controlled the country until the Iranian Revolution in 1979, which emerged from growing dissent and uprising against political repression as well as foreign influences, forcing him to leave the country. The revolution transformed Iran from an absolute monarchy to an Islamic republic with a theocratic constitution under the supreme leader Ayatollah Ruhollah Khomeini. Iran's capitalist economy was replaced by Islamic economic and cultural policies, many industries were nationalized, laws were changed to represent Islamic practice, schools and education were adjusted, and Western influences were banned (Maloney, 2015).

In the aftermath of the revolution, the Iran hostage crisis was a pivotal

event that further deteriorated relationships with the West and had a long lasting impact (Houghton, 2001). On 4 November 1979, a group of Iranian students who belonged to the Muslim Student Followers of the Imam's Line, took over the US embassy in Tehran. They demanded that the Shah, who was in the US for medical treatment, be returned to Iran for trial. Furthermore, they required that the US government apologize for interference in internal Iranian affairs and that it release frozen Iranian assets. Even though the initial plan was to hold the embassy only for a short time, the 52 American embassy employees were kept hostage for 444 days before they were released on 20 January 1981. Due to this crisis, the US and Iran broke off their formal diplomatic relations and have not re-established them up to this day.<sup>4</sup> The hostage crisis and the failed military rescue attempt remain a traumatic experience for the US until today.

In 1980, Iraqi leader Saddam Hussein sought to take advantage of the political and social tumultuous changes in Iran (Razoux, 2015). He was worried that the Iranian Revolution would spill over to Iraq and attempted to position Iraq as the new dominant power in the Middle East. On 22 September 1980, the Iraqi army invaded Iran, starting the Iran-Iraq War. The attack took Iran by surprise. The country's once strong military had been weakened during the revolution. But, even though Iraqi forces made several early advances, they were quickly repelled and pushed back by Iranian forces. The war lasted for eight years. It included the use of chemical weapons by the Iraqi forces and led to hundreds of thousands casualties on both sides (Karsh, 2002). Then, in 1988, a UN-brokered truce was accepted by both sides.

The revolution and the war with Iraq still has a significant impact on the current perceptions of Iranian decision-makers, who in some cases witnessed these violent events first-hand. Some of them became highly suspicious of Western involvement in the Middle East, partly due to the fact that the US and some European states provided military, financial, and political support to Iraq during the war (Juneau & Razavi, 2013). Throughout the 1980s, Iran supported various liberation or opposition movements in the Middle East and North Africa. This support also led to the discontent and anger of several states in the region that were

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<sup>4</sup>Iran initially selected Algeria and later mandated Pakistan for the representation of its interests in the US. Switzerland represents US interests in Iran.

concerned about such involvement (Juneau & Razavi, 2013). Some of them, in particular Saudi Arabia, countered Iran's attempts to influence regional developments until today.

After the death of Khomeini in 1989, the then acting president Ayatollah Ali Khamenei was appointed as new supreme leader of Iran, giving rise to political changes. The new government, under pragmatic conservative president Akbar Hashemi Rafsanjani, focused on the rebuilding of Iran's economy and infrastructure after the war and tried to end Iran's diplomatic isolation in the region (Maloney, 2015). Even though these policies led to some improvements, the general population reacted with disenchantment. After the end of Rafsanjani's second term, the reformist candidate Mohammad Khatami was elected in 1997 as the new president. He further tried to transform the Islamic Republic, both domestically and internationally. But already, a change in tone and rhetoric regarding Iran's foreign policy faced major resistance from conservative forces within the regime, which led to increasing tensions and political blockade during his presidency. Despite his change in tone, Khatami remained critical toward the West and never challenged the main components of Iran's foreign policy such as the attempt to get international acceptance for its right to nuclear technology (Ehteshami & Zweiri, 2008).

During this period, two geopolitical shocks altered the global balance of power. First, the collapse of the Soviet Union deconstructed the bipolar world order and led to a clear supremacy of the US. Second, the First Gulf War (1990 – 1991) led to the defeat of Iraq and the decimation of its powerful army. These changes contributed to leaving Iran and Israel as two powerful states in the region. As the common threat of a powerful and military offensive Iraq had disappeared, Israel's strategists began to argue that, in this new situation, Iran could become an increasing risk (Trita, 2017).<sup>5</sup>

The changing international alignment after the terrorist attacks of 11 September 2001 triggered massive changes in the Middle East. US-led invasions started wars in Iran's neighboring countries Afghanistan (2001) and Iraq (2003), aiming for regime changes. In his state of the union

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<sup>5</sup>Israel has attacked countries in the region multiple times to prevent them from establishing a nuclear program. On 7 June 1981, Israel's air force destroyed near Baghdad an Iraqi nuclear reactor under construction (Tamsett, 2004) and on 6 September 2007, they destroyed a Syrian nuclear reactor under construction in the Deir ez-Zor region (Kershner, 2018).

address in 2002, US President George W. Bush further declared Iran as part of the "axis of evil" which additionally damaged Khatami's efforts by offending conservatives and reformists alike. The perceived failure of the reformist movement opened the way for a new group of conservatives, which led to the election of Mahmoud Ahmadinejad as the new president in 2005. His government introduced a stronger orientation to rising powers, such as Brazil, China, India, Russia, Turkey, and Venezuela, to counterbalance the US, Israel, and their Arab allies and challenge Western dominance (Maloney, 2015). His tone was more aggressive, such as maintaining unacceptable views on historic events, which led to an even bigger isolation of Iran within the international community.

After the end of Ahmadinejad's second term, Hassan Rouhani became the new President in 2013, promising to re-calibrate Iran's relationships with the world (Akbarzadeh & Conduit, 2016). In particular, he promised greater transparency with regard to the nuclear program, aiming to restore international trust. He knew this dossier and its international challenges well because he served as chief negotiator of the Iran nuclear issue from 2003 until 2005.

### **4.1.2. Nuclear Program**

This section provides an overview of a generic nuclear program and the situation in Iran. To help better understand the general situation, the first part introduces the generic structure of a civilian nuclear fuel cycle. The second part provides a historic perspective on Iran's nuclear aspirations. It also describes the development of the Iranian nuclear program up to the implementation of the Joint Comprehensive Plan of Action.

#### **4.1.2.1. The Nuclear Fuel Cycle**

The production of nuclear power relies on the use of fissile material that can sustain a nuclear chain reaction. The most common chemical elements that are used as nuclear fuels for electricity production are uranium and plutonium. The released nuclear energy generates heat, which is then used to power steam turbines to produce electricity. A nuclear fuel cycle is intended to provide fuels for the use in nuclear power plants and comprises the process of producing and processing such materials (Crossland, 2012). Different stages and processes of such a

civilian fuel cycle rely on dual-use technology that can also be used for a possible military dimension of a nuclear program that is intended to build nuclear weapons.

The first stage of the fuel cycle is mining of uranium ore, which is later milled to separate the uranium from the ore. To make it useful, the extracted uranium is further processed and converted. Natural uranium consists largely (relative abundance of about 99.3%) of the isotope 238 ( $^{238}\text{U}$ ) and only slightly (relative abundance of about 0.7%) of the lighter isotope 235 ( $^{235}\text{U}$ ) (Cowan & Adler, 1976). Only this lighter and less stable uranium isotope can undergo an induced fission chain reaction and, therefore, has to be accumulated to be further used.<sup>6</sup> To make enrichment possible, the milled uranium oxide must be converted into uranium hexafluoride ( $\text{UF}_6$ ) gas. This  $\text{UF}_6$  can be enriched in gas centrifuges (Crossland, 2012). The enriched  $\text{UF}_6$  is reconverted and manufactured into reactor fuel, usually in the form of ceramic pellets. This fuel is then used in a nuclear reactor until it reaches the stage where the  $^{235}\text{U}$  cannot be further burned. The spent fuel is removed and reprocessed. After it is cooled for a few years, it can be separated into uranium, plutonium<sup>7</sup>, and nuclear waste. The reprocessed uranium can then be reused and again be converted into  $\text{UF}_6$ . Figure 4.2. illustrates such a generic civilian nuclear fuel cycle.

##### 4.1.2.2. The Iranian Nuclear Program

The foundation of Iran's nuclear program was laid in 1957 with the support of the US, when the two countries signed an agreement for cooperation on the peaceful uses of atomic energy. This act was part of the "Atoms for Peace" program that was launched by US President Dwight D. Eisenhower in 1953, to spread the use of nuclear technology for civilian use to countries that were politically close to the US (Gaietta, 2015). In 1960, Iran purchased a 5 megawatt (MWe) research reactor, which first went critical in 1967, using highly (93%) enriched Uranium fuel, supplied by the US. Iran ratified the Nuclear Non-Proliferation Treaty (NPT) in 1970 (Joyner, 2016), whereby it agreed not to become a

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<sup>6</sup>For use in nuclear power plants, the proportion of  $^{235}\text{U}$  has to be increased up to 5%, where for the production of nuclear weapons it must be enriched to more than 80%.

<sup>7</sup>Plutonium can be combined with uranium to create mixed oxide fuel, or it can be used for military purposes.

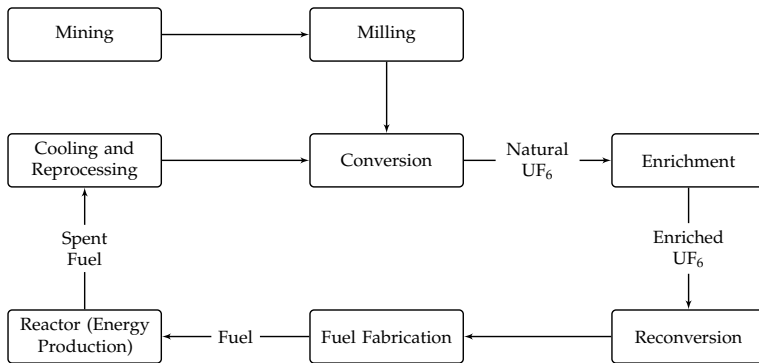


Figure 4.2.: A generic civilian nuclear fuel cycle

nuclear weapon state and made its nuclear program subject to verification by the International Atomic Energy Agency (IAEA). The Shah was aware that the oil supplies would run out some day and, in 1974, announced his intention to generate 23'000 MWe at nuclear power plants "as soon as possible"<sup>8</sup>. Various plans for the purchase of nuclear technology were agreed upon with France, the Federal Republic of Germany, and the US. In 1975, a German company started to construct the first of two 1200 MWe nuclear reactors in Bushehr. Iran further intended to establish a complete nuclear fuel cycle, including the enrichment of uranium and the reprocessing of spent fuels, both of which are dual-use activities that can also be used for a military dimension of the nuclear program.

After the Iranian Revolution, most of the international cooperation regarding the nuclear program was stopped (Poneman, 1982). In 1979, the German Siemens subsidiary terminated its construction at the Bushehr Nuclear Power Plant project, because Iran did not pay its overdue payments of USD 450 million (Patrikarakos, 2012). The project was not finished at that time. Most of the reports indicated that the first reactor was 75% – 85% complete, the second reactor was 45% – 70% complete,

<sup>8</sup>"The oil we call the noble product will be depleted one day. It is a shame to burn the noble product for the production of energy to run factories and light houses. [...] We plan to get, as soon as possible, 23'000 MWe from nuclear power stations" (Poneman, 1982, p. 85-86)

and about 90% of the parts had been shipped to Iran (Poneman, 1982; Williams & Viotti, 2012). The US further stopped the supply of enriched uranium for the research reactor, which forced the Iranians to shut it down for a number of years.

In the first years after the revolution, the nuclear program was not a priority for Khomeini. Only in the mid-1980s, during the conflict with Iraq, the government increased its investment in the program. During that time, the two unfinished reactors at Bushehr were attacked and damaged. In the presence of a developing Iraqi nuclear program and with the realization that Iraqi forces used chemical weapons under the rather indifferent eyes of the international community, there was an increasing concern about possible Iraqi nuclear ambitions (Patrikarakos, 2012). This led to an emerging belief of a strategic need to balance its neighbor by providing some sort of deterrence (Gaietta, 2015). The ongoing international isolation further reinforced the attempts to establish a complete nuclear fuel cycle, which would reduce the dependency from foreign suppliers. This guiding principle of self-sufficiency was additionally encouraged by the discovery of natural uranium in Iran after several years of exploratory work. As nuclear cooperation with the West was mostly severed, Iran oriented itself toward other actors with nuclear know-how such as Argentina, China, Pakistan, and Russia (Joyner, 2016).

After the end of the Iraq-Iran war in 1988, the nuclear cooperation between Iran and Pakistan started to increase. Relying on the Network of Abdul Qadeer Khan, the founder of the Pakistani nuclear weapons program, Iran started to build its enrichment program according to the Pakistani design of gaseous centrifuge technology (Pollack, 2013). This technical cooperation with A.Q. Khan was important for Iran and endured until 1999. The first generation of Iranian centrifuges (IR-1) are based on the design of the Pakistani P-1 (Alam, 2004).<sup>9</sup> Later, more advanced centrifuge models, which have a much higher enrichment output compared to the first design, such as the IR-2, IR-3, and IR-4, were derived from Pakistani's P-2 centrifuge.

After the fall of the Soviet Union, Iran established closer nuclear cooperation with Russia. There was a strong intention to transfer know-how and to build new nuclear power plants (Gaietta, 2015). Although there were

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<sup>9</sup>The IR-1 centrifuges constitute the vast majority of the Iranian centrifuges. An overview is presented in the Appendix *Iran Nuclear Program Database* on page 111.



different deals with China and Russia to build new power plants, the only agreement that was realized was concerning the Bushehr Nuclear Power Plant. In 1995, Iran signed a contract with Russia to repair and complete the still unfinished Bushehr Nuclear Power Plant (NTI, 2011). A new Russian 1'000 MWe reactor was shipped in 2001 to be installed in place of the old German 1'200 MWe reactor.

At the end of the 1990s and until the beginning of the 2000s, Iran built the majority of its nuclear plants (e.g., conversion, enrichment, and production plants) that are now in function or still under construction (Gaietta, 2015). From the early 2000s, Iran began to plan a 40 MWe heavy water<sup>10</sup> research reactor (labeled IR-40) near Arak and started construction in 2004 (Joyner, 2016).

In 2002, an Iranian dissident group against the Islamic regime, the National Council of Resistance of Iran (NCRI), publicly revealed the existence of two secret nuclear plants under construction (Patrikarakos, 2012). One was the Arak Heavy Water Production Plant. The other one was the Natanz Enrichment Plant. It consisted of a Pilot Fuel Enrichment Plant (PFEP), which could house up to 1'000 centrifuges, and an industrial Fuel Enrichment Plant (FEP), which was designed to house up to 48'000 IR-1 centrifuges. The halls of the enrichment plants were built underground to defend them from a conventional attack.

After the revelation, the International Atomic Energy Agency (IAEA) requested further information, access to these facilities, and insisted on the full cooperation by the Iranian government regarding its nuclear program in agreement to its commitments toward the IAEA under the NPT (Joyner, 2016).<sup>11</sup> The IAEA inspections were inconvenient for Iran because they could shed light on the development of enrichment activities

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<sup>10</sup>A heavy water reactor commonly uses unenriched natural uranium as fuel and heavy water (deuterium oxide D<sub>2</sub>O) as coolant and neutron moderator. This allows the reactor to operate without fuel enrichment facilities. At the same time, heavy water reactors pose a greater risk of nuclear proliferation than comparable light-water reactors. The reason is that they allow accumulation of significant amounts of plutonium 239 (<sup>239</sup>Pu), which is a fissile material that is suitable for the use in nuclear weapons. In this way, it is possible to obtain materials that are necessary for the construction of nuclear weapons without any uranium enrichment.

<sup>11</sup>According to the arrangements at that time, Iran only had to allow IAEA inspections to a new facility at least six month before nuclear material was introduced into that facility (Joyner, 2016). Only after Iran accepted the additional protocol of the NPT in 2003, as one of the last signatory states to the NPT, and after the IAEA investigation began, Iran had to report facilities already during the planning phase.

and, therefore, force them to explain all other undeclared activities in this field (Gaietta, 2015).

Iran postponed a planned visit by the IAEA several times until the beginning of 2003. This visit showed that the Iranian declaration was incomplete. In the same year, NCRI revealed the existence of two other previously undisclosed nuclear-related sites. Under increased pressure from the IAEA, the imminent risk for potential deferral to the UNSC, and in the light of the uncovering of A.Q. Khan's network and its active role in nuclear weapons technology proliferation to North Korea, Iran, and Libya, Tehran agreed to extend the cooperation with the IAEA and to clarify different aspects of its nuclear program (Gaietta, 2015). The Iranian government placed the nuclear dossier under one single authority that was respected by the military, scientific, and political entities. This strategic committee within the Supreme National Security Council was headed by Hassan Rouhani, Iran's first nuclear negotiator.

Iran repeatedly affirmed that its nuclear program was strictly peaceful and that it had no intention to build nuclear weapons. Even though a civilian nuclear fuel cycle and notably also enrichment are allowed under the NPT, multiple diplomatic efforts were made to keep Iran from expanding its nuclear program. These attempts had little success, and Iran continued to increase its nuclear program.

After the election of Mahmoud Ahmadinejad in 2005, tensions increased (Ehteshami & Zweiri, 2008). Iran contentiously expanded its enrichment capability. In 2009, Iran informed the IAEA that it decided to build another enrichment facility. It became apparent that construction of this plant, the Fordow Fuel Enrichment Plant (FFEP), had already started some time ago, and was concealed at great depth in a remote mountainous area.

Over the next several years, the enrichment capacities and especially the number of centrifuges continuously increased. Figure 4.3. illustrates this development. It shows the total number of installed centrifuges and the operating centrifuges that are fed with UF<sub>6</sub> for enrichment. A detailed overview of the enrichment capacity and its development over time is presented in *Iran Nuclear Program Database* on page 111, which builds the basis for this analysis.

In parallel to this increased enrichment capacity, Iran started to produce enriched uranium. Figure 4.4. illustrates the development of production and stockpiles. In 2008, Iran started with the accumulation of up to

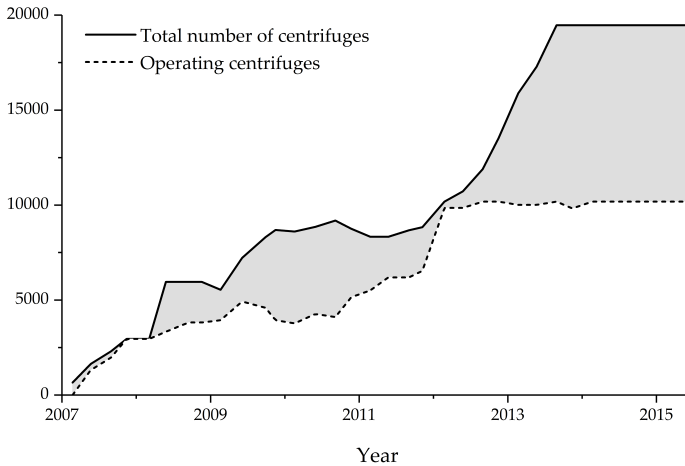


Figure 4.3.: Number of Iranian centrifuges installed and operating with  $\text{UF}_6$  based on data from the IAEA

5% enriched  $\text{UF}_6$  for the manufacturing of nuclear fuel, as illustrated in Figure 4.4a. Subsequently in 2010, Iran commenced with the production of higher, up to 20%, enriched  $\text{UF}_6$  for research and medical purposes, as illustrated in Figure 4.4b. The production and stockpiling of both categories of enriched uranium increased until the end of 2013. A detailed overview of the enrichment activities and stockpiles of enriched material over time is presented in the *Iran Nuclear Program Database* on page 111.

In 2007, Russia announced its decision to finish the Bushehr Nuclear Power Plant after delays to the project (Gaietta, 2015), which occurred also due to political pressure. Russia started to deliver nuclear fuel to the site and it became an active nuclear facility in 2010, when the fuel was loaded into the plant. In 2012, the power plant was connected to the national power grid, and in 2013, the commercial production of electricity began.

In 2011, the IAEA publicly and in detail outlined its concerns about Iranian activities related to the development of nuclear weapons (IAEA, 2011), mentioning 12 main areas necessary for investigation. These possible military dimensions of Iran's nuclear program dated to some extent

## 4. Iran Nuclear Dispute

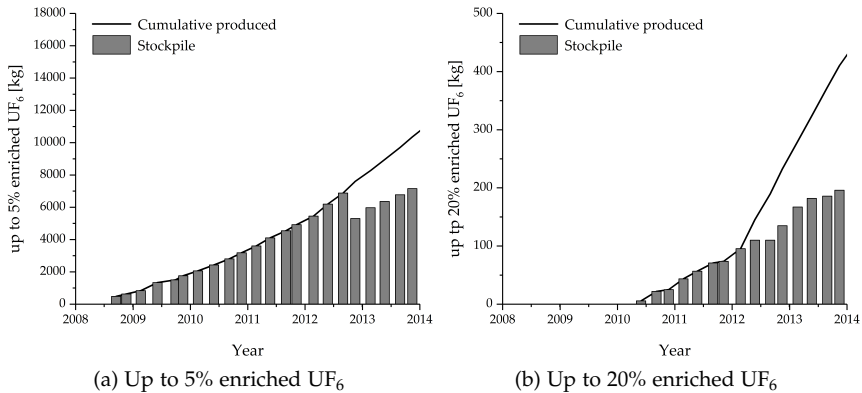


Figure 4.4.: Production and stockpile of enriched  $UF_6$  based on data from the IAEA

back as far as the late 1980s. From 2002 onwards, the IAEA was increasingly concerned about the possible existence of undisclosed nuclear-related activities, including activities that were related to the development of nuclear weapons. Little progress was made to resolve these concerns, until November 2013, when Iran and the IAEA announced a framework for cooperation to address the IAEA's concerns. This framework was later superseded by the 2015 Road-map for the Clarification of Past and Present Outstanding Issues regarding Iran's Nuclear Program (IAEA, 2015b).

The final assessment, released at the end of 2015, stated that all activities to clarify the raised concerns were implemented in accordance with the agreed schedule. The IAEA concluded that Iran had carried out activities aimed at developing nuclear weapons prior to 2003. These activities were part of a structured program that ended in 2003, but some activities might have continued until 2009 (IAEA, 2015a). According to the assessment, *"these activities did not advance beyond feasibility and scientific studies, and the acquisition of certain relevant technical competences and capabilities"* (IAEA, 2015a, p.14). The IAEA further stated that it *"found no credible indications of the diversion of nuclear material in connection with the possible military*

*dimensions to Iran's nuclear programme*" (IAEA, 2015a, p. 15).

### 4.1.3. Sanctions

After the revelation of Iran's uranium enrichment program in 2002, concerns were raised regarding its potential non-peaceful purpose. To disincentivize Iran's nuclear activities and ensure adherence to the Non-Proliferation Treaty, the US, the UNSC, and the European Union (EU) imposed numerous sanctions against Iran.

This section provides an overview of these specific sanction activities. Sanctions have also been issued against Iran by other countries, such as Australia, Canada, India, Israel, Japan, South Korea, and Switzerland. However, sanctions by the US, the EU, and the UNSC have been by far the most significant. Figure 4.5 illustrates the number of sanction provisions by the US, EU, and UNSC over the period beginning 2005 until the end of 2014. For this analysis, the initial legislation or executive acts are considered, as well as the sanction extensions, which extend the effect and build on previous decisions. A full list of all these provisions is presented in *Iran Sanction Database* on page 114. All information was collected from official government sources.

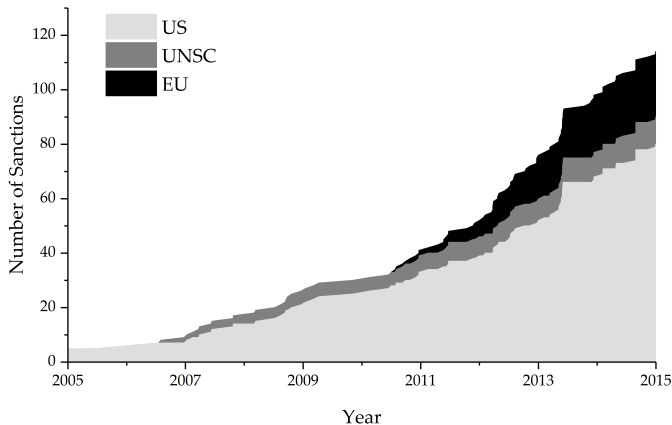


Figure 4.5.: Number of sanction provisions by the US, the EU, and the UNSC

### 4.1.3.1. **United States Sanctions**

Subsequent to the Iranian Revolution in 1979 and triggered by the Iran hostage crisis, the US introduced the first sanctions against Iran, freezing Iranian assets of about USD 12 billion (Maloney, 2015). During the Iran-Iraq War, the US further increased their sanctions, prohibiting assistance and weapons sales. In 1995, the US prohibited any trade with Iran, focusing on the oil industry. Later in 1996, the Iran and Libya Sanctions Act (ILSA) was passed, imposing economic sanctions on firms doing business with Iran and Lybia.<sup>12</sup> In response to the elections of President Mohammad Khatami, some sanctions were eased, but the relationship between the US and Iran remained tense (Maloney, 2015).

After the election of President Ahmadinejad and as a response to the advancement of the Iranian enrichment program, President George W. Bush issued Executive Order 13382 in 2005. It directly targeted individuals who were connected to the Iranian nuclear program and built the foundation for many of the later sanction provisions. In 2006, the US imposed sanctions on the largest bank in Iran, prohibiting it, even indirectly, from dealing with US financial institutions. In 2007, four other Iranian banks were added to this expulsion. In 2010, the US Congress passed the Comprehensive Iran Sanctions, Accountability, and Divestment Act that greatly enhanced restrictions on Iran and especially on the oil and gas sector, followed by different executive orders. In 2012, additional executive orders were signed by President Obama, targeting the Iranian national bank as well. The US continually increased its pressure to almost a total economic embargo and introduced sanctions against foreign firms that were doing business with Iran. In the period from 2005 to 2014, multiple new sanction provisions were introduced every year.

### 4.1.3.2. **European Union Sanctions**

The EU first issued its own sanctions against Iran in 2010. It introduced the freezing of funds, prohibited the sale of weapons and dual-use technologies, and targeted the oil and gas sector. In 2012, it announced an embargo on the Iranian oil exports, adding extensive restrictions on foreign trade and the financial sector. As a result, the Society of Worldwide

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<sup>12</sup>In 2006, the ILSA was renamed to Iran Sanctions Act (ISA), when it no longer applied to Libya.

Interbank Financial Telecommunication (SWIFT) expelled Iranian financial institutions, including the Iranian National bank, from its system and thereby extensively constrained the institutions' ability to conduct international business.

The EU continually increased pressure on Iran until the end of 2014. These sanctions strongly reduced the economic relationship between the EU and Iran. In 2011, the EU had EUR 17.3 billion worth of imports and more than EUR 10.5 billion worth of exports to Iran, which dramatically decreased in 2013 to only EUR 0.8 billion in imports and EUR 5.4 billion in exports (European Commission, 2017).

#### **4.1.3.3. United Nations Security Council Sanctions**

The UNSC passed several resolutions as part of international efforts to address Iran's nuclear program. These resolutions followed the report by the IAEA about Iran's non-compliance and lack of clarity about its nuclear program. In 2006, the UNSC adopted the first resolution, demanding that Iran suspend its enrichment activities. The resolution was followed by a second one in the same year, imposing sanctions under Article 41 of Chapter VII of the Charter of the United Nations, which was legally binding for all UN member states.

The following UNSC resolutions were passed with regard to Iran up to and including 2014:

- *Resolution 1696* (2006) demanded that Iran must suspend all enrichment-related and reprocessing activities within one month. The resolution did not impose sanctions, but threatened that the UNSC would "adopt appropriate measures under Article 41 of Chapter VII of the Charter of the United Nations" if Iran failed to comply.
- *Resolution 1737* (2006) maintained the previous demands and obliged all member states to adopt measures to prevent the supply, sale, or transfer of materials to Iran that could be used for nuclear or ballistic missile programs. The resolution further called on member states to freeze the financial assets of key individuals and corporations related to these programs.
- *Resolution 1747* (2007) imposed an arms embargo on Iran and further expanded the freezing of financial assets. It also called on member

states and global financial institutions not to enter into new financial commitments with Iran's government except for humanitarian and developmental purposes.

- *Resolution 1803* (2008) extended the asset freeze and imposed travel restriction. It also called on states to monitor the movements of individuals who were involved in the programs to inspect Iranian aircraft and ships and "exercise vigilance" when providing export credits, guarantees, and insurance to Iranian entities.
- *Resolution 1835* (2008) did not set up new sanctions but reaffirmed the previous four resolutions.
- *Resolution 1929* (2010) prohibited Iran from undertaking any activities related to ballistic missiles. It required member states to prevent the transfer of missile-related technology to Iran and tightened the arms embargo. It prohibited Iran from investing in nuclear and missile technology abroad and further enhanced previous travel and financial sanctions.
- *Resolution 1984* (2011) extended the mandate of the panel of experts that was established by Resolution 1929 to support the Iran sanctions committee, by one additional year.
- *Resolution 2049* (2012) extended the mandate of the panel of experts that was established by Resolution 1929 to support the Iran sanctions committee, by one additional year.
- *Resolution 2105* (2013) extended the mandate of the panel of experts that was established by Resolution 1929 to support the Iran sanctions committee, by one additional year.
- *Resolution 2159* (2014) extended the mandate of the panel of experts that was established by Resolution 1929 to support the Iran sanctions committee, by one additional year.
- *Resolution 2231* (2015) endorsed the Iran nuclear deal and lifted previous sanctions on Iran, given that Iran remains in compliance with its responsibilities under the nuclear deal.



## 4.1.4. Negotiations

### 4.1.4.1. History of Negotiations

Besides the unilateral and multilateral coercive means to prevent a nuclearization of Iran, multiple diplomatic initiatives have taken place to find a solution to the conflict. In 2003, according to a Swiss diplomat, Iran issued a proposal to the US, calling for direct talks between the two countries (Kessler, 2007). They proposed negotiations on various contentious issues, including disarmament, terrorism, and regional security, as well as economic cooperation (relief of all US sanctions). But, the Bush administration dismissed the proposal (Arms Control Association, 2015).

Later in 2003, France, Germany, and the United Kingdom (EU3) started negotiations to ensure that Iran complied with its obligations under the NPT and would not develop nuclear weapons (Arms Control Association, 2015). This first multilateral negotiations resulted in a joint statement (the "Tehran Declaration"), in which Iran stated that it would sign the IAEA Additional Protocol and agreed to voluntarily suspend all uranium enrichment and reprocessing activities. The EU3 on their part recognized the right of Iran for the peaceful use of nuclear energy in accordance with the NPT (Tehran Declaration, 2003). These negotiations were continued in February 2004 in Brussels and stated an understanding in which Iran agreed to halt the manufacturing and assembling of centrifuges. The EU3 agreed to push for a normalization of the Iran file within the IAEA Board of Governors meeting. However, Iran perceived the EU3 to have failed to deliver diplomatic results and then ended the suspension of the enrichment activities (Joyner, 2016).

In November 2004, in an endeavor to continue the negotiations, the two sides signed the Paris Agreement, which provided a basis for a long-term solution. The EU3 recognized Iran's rights under the NPT without discrimination—the full right for the peaceful use of nuclear technology, including a nuclear fuel cycle. Iran voluntarily agreed to suspend all enrichment-related and reprocessing-related activities, including the installation of centrifuges, for the time during which negotiations on a mutually acceptable long-term agreement proceeded (IAEA, 2004). Furthermore, the agreement set up working streams looking for cooperative arrangements on political and security issues, technology and cooperation, and nuclear issues, for further negotiations.

The Paris Agreement had positive initial effects. After the agreement, the IAEA inspectors confirmed that a full suspension was in place, and the IAEA Board of Governors decided not to refer Iran to the UNSC (IAEA, 2018). For some months, expectations were high that the negotiations would lead to an overall diplomatic solution. However, the negotiations failed in 2005 after the two parties were unable to come to an agreement with regard to a long-term solution. Iran was concerned that the negotiations were not making visible progress. It submitted a discussion paper to the EU3, in which it proposed to resume some of the enrichment activities under close monitoring. Starting with 500 centrifuges at their pilot plant, the number could increase over time to three thousand centrifuges (ElBaradei, 2011). The EU3 delayed responding to this proposal, partially due to pressure from the US, to halt the enrichment activities permanently. The EU3 responded only some months later in vague language regarding their support and asked Iran to eliminate its nuclear facilities entirely (Joyner, 2016). Shortly after the election of Mahmoud Ahmadinejad, and before receiving this proposal, Iran began to communicate that it would not continue with full suspension. Iran started to produce UF<sub>6</sub> for enrichment, and the EU3 halted negotiations (Arms Control Association, 2018).

In September 2005, the IAEA adopted a resolution in which it found Iran in noncompliance with its safeguard agreements and stated that Iran's nuclear activities fall under the domain of the UNSC (IAEA, 2018). In February 2006, Iran informed the IAEA that it would resume its uranium enrichment research and development (Arms Control Association, 2018). Subsequently, the IAEA referred the Iranian case to the UNSC. In response, Iran announced that it will stop the voluntarily implementation of the additional protocol (which had not been ratified by the Iranian parliament) and that it will also end all cooperation with the IAEA, going beyond the legally binding agreements (Joyner, 2016). The positions between Iran and the West became harder, especially when the US insisted on the hard-line stance that "not one centrifuge" could operate in Iran (ElBaradei, 2011).

It became obvious that the permanent members of the UNSC<sup>13</sup>, and particularly in the US, would have to be included in further negotiations

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<sup>13</sup>China, France, Russia, the United Kingdom, and the United States

with Iran. Therefore, the group was extended to EU3+3<sup>14</sup>, which is equivalent to the P5+1<sup>15</sup>.

In June 2006, the P5+1 and the EU, under the leadership of the High Representative for the Common Foreign and Security Policy, Javier Solana, offered a proposal for comprehensive negotiations with Iran. It included some of the same elements as previous proposals and additional incentives (High Representative for the Common Foreign and Security Policy, 2006). Iran replied that it needed more time to respond, while continuously increasing the number of installed centrifuges. The request for more time was viewed critically by some countries. The US suspected that Iran would use this time to increase its enrichment capacity (ElBaradei, 2011). In late July 2006, the UNSC passed its first resolution against Iran. Iran ultimately rejected the P5+1 proposal, announcing that it would never agree to completely suspending its enrichment activities. Over the next month, Javier Solana, on behalf of the P5+1, attempted to negotiate with Iranian representative Ali Larijani. However, no agreement was reached, and the UNSC passed its second resolution, issuing sanctions against Iran. The road to a possible agreement seemed blocked (Trita, 2017).

In April 2007, Switzerland, the protecting power of US interests in Iran, offered its support to re-launch negotiations (Ambühl, 2016; Langenegger & Ambühl, 2018). The proposed document consisted of both diplomatic-procedural and thematic proposals. The diplomatic-procedural proposal contained confidence-building measures, including the *freeze for freeze* concept, stating that P5+1 would not table any new sanctions and Iran would not develop new nuclear enrichment-related activities. The proposal also included guiding principles for the negotiations and a phased approach for the talks. The thematic proposal regulated further development of the enrichment activities, but the two parties could not agree to re-start the negotiations.

Only in June 2008, did the P5+1 present a revised package of the June 2006 proposal, leading to the understanding that preliminary talks could begin under a six-week freeze-for-freeze period (Arms Control Association, 2018). One month later, the Geneva Talks were held between Iran and the P5+1 in Switzerland. It was the first high-level meeting between the US and Iran since the termination of their diplomatic relations

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<sup>14</sup>France, Germany, and the United Kingdom plus China, Russia, and the United States

<sup>15</sup>The five permanent members of the UNSC (China, France, Russia, the United Kingdom, and the United States) plus Germany

in 1979 (Kessler, 2008; Ambühl, 2016; Langenegger & Ambühl, 2018). Despite the success of direct negotiations, the talks remained inconclusive.

In 2009, the new US administration under President Obama announced that it would fully participate in the P5+1 talks with Iran, without any preconditions (Arms Control Association, 2018). Later that year, during a second round of talks in Geneva, negotiations started over a Fuel Swap proposal, according to which Iran would export 1'200 kg of 3.5% enriched uranium in return for 120kg of 20% enriched fuel rods (Arms Control Association, 2018). This trade would reduce Iran's stockpile of low-enriched uranium, which provides the source for higher enrichment and furnishes nuclear fuel that cannot easily be further enriched. However, this agreement was not concluded.

In 2010, the pressure was increased. The UNSC significantly expanded its sanctions in Resolution 1929; the US Congress adopted the Comprehensive Iran Sanctions, Accountability, and Divestment Act; and the EU first issued own sanctions against Iran. Furthermore, Stuxnet, a malicious computer worm that specifically targeted and damaged the Iranian nuclear program, was first exposed (Bjola, 2016). Older versions were uncovered that were developed as early as 2005 and used to attack Iran's nuclear program since November 2007 (Middleton, 2017).

In July 2011, Russia proposed a phased road-map to increase cooperation between Iran and the IAEA in return for a gradual reduction of sanctions (Arms Control Association, 2018). Although Iran welcomed the proposal and the US showed interest, the proposal did not gain traction.

In the first half of 2012, several talks were held between the P5+1 and Iran in Istanbul, Baghdad, and Moscow to negotiate a phased process and reciprocal actions (Arms Control Association, 2018). Two proposals, one from P5+1 and one from Iran, were discussed, and both sides agreed on expert-level talks to clarify further details. But, the situation remained tense. In September 2012, in his speech to the UN General Assembly, Israeli Prime Minister Benjamin Netanyahu drew a red-line for an Israeli attack on Iran (Gladstone & Sanger, 2012). He defined this line as accumulating enough (approximately 250kg) of 20% enriched uranium for one bomb, when being further enriched.

In 2013, Iran and P5+1 held talks in Kazakhstan (Arms Control Association, 2015). Both sides presented their proposals, which were based on the ones from 2012 but partly considered also factors which the other side demanded. Nevertheless, after the second round of talks in Kazakhstan,

the two sides announced that they remained far apart and that no further meetings were scheduled (ElBaradei, 2011).

Shortly after the election of Hassan Rouhani as new president of Iran in June 2013, he called for the serious renewal of negotiations with P5+1. In September 2013, on the sideline of the UN General Assembly, the new Chief Negotiator of Iran for the Nuclear Issue, Mohammad Javad Zarif, met with US Secretary of State John Kerry for a first bilateral exchange after they had a meeting in a larger group. The next day, President Barack Obama called Iranian President Hassan Rouhani, which marked the highest level of contact since 1979 (Wilson & Lynch, 2013).

In October 2013, the parties met in Geneva to discuss a new proposal that outlined the broader framework for a comprehensive final agreement and confidence-building steps to take in a first-phase interim agreement. The discussions were described by both sides as substantive and forward looking (Entessar & Kaveh L. Afrasiabi, 2015). The parties continued their negotiations in Geneva in the beginning of November. As they were expecting to close a deal, the P5+1 foreign ministers joined the negotiation. However, the parties failed to reach an agreement but announced that they would continue to negotiate in two weeks' time. The parties met again in Switzerland to continue the negotiations and the foreign ministers joined on 23 November. One day later, the two sides signed the Geneva interim agreement, called the *Joint Plan of Action* (JPOA). This agreement consisted of a short-term freeze on escalation as the parties worked toward a long-term agreement. It defined specific steps for a six-month period (which can be extended) and a broad framework to guide the negotiations for a comprehensive solution. During this time, Iran would fully cooperate with the IAEA, halt the installation of new centrifuges, and reduce its stockpile of 20% enriched uranium. P5+1 would not issue any new nuclear-related sanctions. However, it would suspend sanctions on petrochemical exports, ease other restrictions (e.g., licensing the supply of spare parts for the flight safety for Iranian civil aviation), and facilitate humanitarian trade.

In the beginning of 2014, Iran and the P5+1 met again in Geneva to discuss the implementation and later announced that it would start on 20 January. The parties met six times from February to July in Vienna to negotiate a comprehensive nuclear agreement but failed to conclude the negotiations (Arms Control Association, 2018). They finally announced that they would extend the talks with a new deadline of 24 November.

Up until this new deadline, four additional rounds of negotiations occurred in New York, Vienna, Muscat, and again in Vienna. The tenth round of negotiations under the JPoA failed to cut a deal due to wide gaps on the different positions, but the parties agreed to a second extension with a new deadline extended to 30 June 2015 (IAEA, 2018).

The parties met again under this new extension in Geneva for three further rounds of negotiations. This meeting was followed by a series of intensive talks from March to April in Lausanne at the level of foreign ministers (Arms Control Association, 2018). The talks ended with the announcement that the parties had reached an agreement on a framework deal for Iran's nuclear activities. It served as a precursor for a final agreement that had to be completed by the end of June.

The talks were resumed in Vienna, but the deadline of 30 June passed again without an agreement. Nevertheless, the negotiations continued, and the parties extended the deadline several times. Finally on 14 July 2015, the *Joint Comprehensive Plan of Action* (JCPoA) was signed. It was formally adopted in October 2015 and implemented in January 2016.

##### **4.1.4.2. The Joint Comprehensive Plan of Action**

The JCPoA was reached on 14 July 2015 between Iran, the P5+1, and the EU. This agreement consists of 159 pages (including all annexes) that regulate in detail the development of the Iran nuclear program, monitoring and verification, dispute resolution mechanisms, and sanction reliefs.

After the signing of the JCPoA all parties had to endorse it. It was approved by the UNSC and 90 days later formally adopted. On adoption day 15 October 2015, the JCPoA came into effect and the participants took steps to implement their commitments. The EU adopted regulations to terminate nuclear-related sanction and the US President issued sanction waivers that would go into effect on implementation day. Iran disassembled and removed more than 13'000 excess centrifuges, reduced its stockpile of low-enriched uranium, converted the Fordow enrichment site, removed and disabled the core of the IR-40 heavy-water reactor, and made the necessary arrangement for additional IAEA access and monitoring. All the agreed commitments were finally implemented on 16

January 2016. Figure 4.6. shows the key restrictions<sup>16</sup> on Iran's nuclear program, implemented through the JCPOA, and their agreed duration.

The detailed requirements of the agreement include elimination of 90% of Iran's stockpile of low-enriched uranium (LEU). Also, for next 15 years, it limits the amount of LEU that Iran could possess to 300 kg.<sup>17</sup> Additionally, the amount of heavy water, which contains traces of plutonium, has to be below 130 tons and produced excesses must be exported. The agreement further demands the numbers of centrifuges to be reduced to 6'104 IR-1 centrifuges, of which no more than 5'060 can enrich for the first 10 years. Enrichment will solely be carried out at Natanz. The other important enrichment site, Fordow, must be closed, or rather be converted into a nuclear physics and technology research center. Additionally, the heavy water reactor IR-40 must be modernized and transformed into a light-water reactor.

Iran agrees for the next 25 years to regular and rigorous monitoring of all facilities involved in the nuclear program by the IAEA and an unrestricted implementation of the Additional Protocol of the NPT. This monitoring includes, for example, access on short-notice and monitoring cameras installed at certain facilities.

In return, Iran will get recognition of its right to enrich uranium for peaceful purposes and to develop a civilian nuclear program with international cooperation. If the IAEA reports that Iran has fulfilled the requirements, various sanctions imposed by the US, the UNSC, and the EU will be lifted. These include the export of all petrochemical products, general access that is granted for export goods, lifting the ban on international financial activities, and the release of capital reserves from former oil sales amounting up to USD 100 billion.

Even though part of the sanctions were lifted, sanctions regarding, for example, terrorism and human rights violations, will be upheld. The US and the UN reserved the right to enforce further sanctions in these matters if necessary. These sanctions mainly include a ban on selling military equipment and freezing assets of individuals known to support terrorism.

The JCPOA further includes a dispute resolution system. If one party believes that the other is not holding up its commitments to the agreement,

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<sup>16</sup> According to the author's assessment.

<sup>17</sup> The stockpile of LEU (up to 5%) at time of the agreement was around 8000 kg.

#### 4. Iran Nuclear Dispute

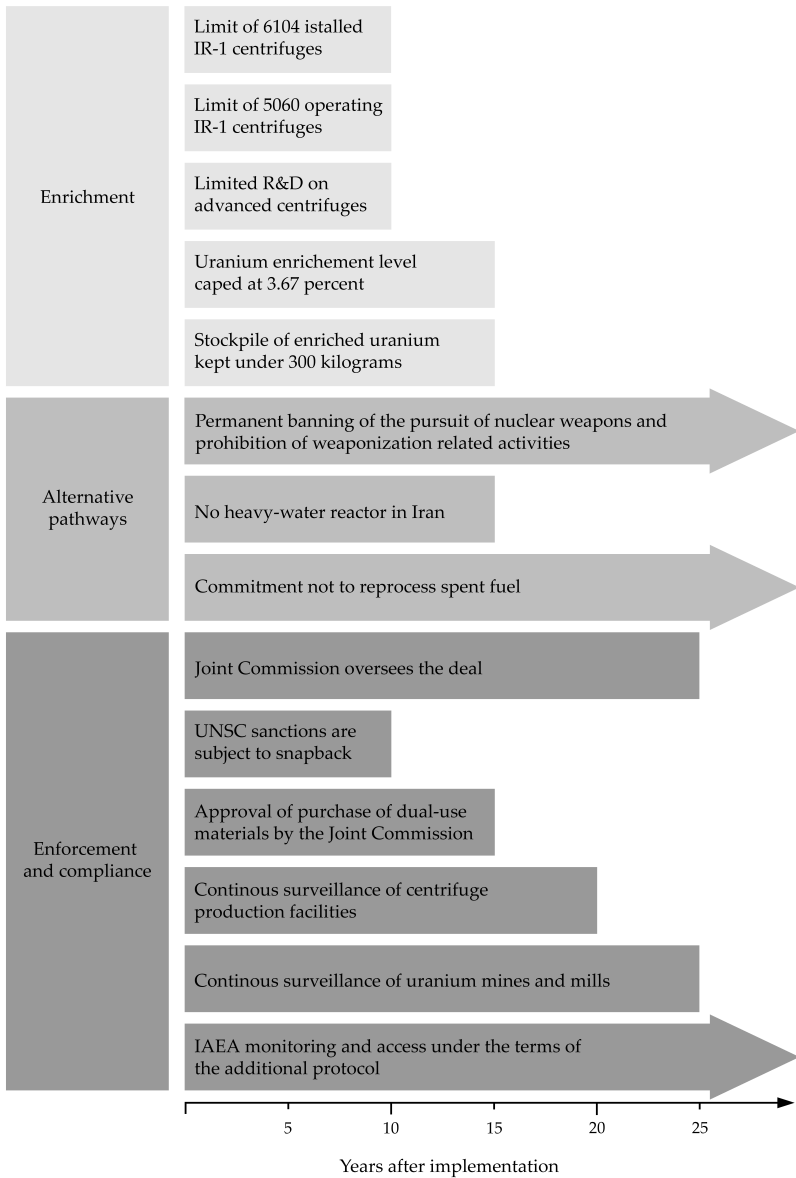


Figure 4.6.: Key restrictions of the JCPoA and their duration



it can refer the issue to the Joint Commission, which consists of members of all involved parties. The Commission then has 15 days to resolve the matter unless this period is extended by consensus. If the issue cannot be resolved by the Commission within this time, the problem is further referred to the ministers of foreign affairs of the involved parties for another 15 days. At the same time, an advisory board is formed to provide a non-binding opinion to solve the matter for the joint commission to consider. After this 30-day period, the joint commission has up to 5 days to consider the option provided by the advisory board. If the issue still cannot be resolved, the involved parties can treat the unresolved issue as grounds to cease performing its commitments to hold up the agreement. If noncompliance occurs, any party can go to the UNSC to put sanctions back in place.

#### **4.1.5. Conclusions**

After revelations of Iran's nuclear program were made known, concerns were raised about its possible non-peaceful purpose. Even though Iran always affirmed the purely peaceful character of its nuclear program, questions were raised regarding its non disclosure and hesitant cooperation with the IAEA. Iran insisted on its right to the peaceful use of nuclear technology whereas the other side tried to minimize the risk of nuclear proliferation. Even though negotiations started early to ensure Iran's right to enrich nuclear fuel for civilian purposes under the NPT and that it would not develop nuclear weapons, it took years to come to a comprehensive agreement.

During this time, ongoing escalation occurred on both sides, with an extension of the nuclear program and an increase in sanctions. This escalation was hurtful and dangerous, implicating the possibility to trigger military events. Only in the end, an agreement was reached that avoided the dual danger of war and of a nuclear-armed Iran.

Looking at the conflict, the data of economic sanctions and installed centrifuges for the enrichment of uranium can be used as quantitative measures for its development. Sanctions can be seen as a direct implementation of pressure. Even though the strengths of the sanctions are not incorporated into this analysis, the change in quantity already gives insight into the development of coercion. Alternatively, the number of installed centrifuges seems to be a suitable measure for the development

of the Iranian nuclear program, because it directly correlated with the capacity to enrich uranium and the break-out time to develop nuclear weapons material. Moreover, both measures played an integral role in the negotiations and final agreement. Figure 4.7. shows the cumulative sanctions by the United States, the European Union, and the United Nations Security Council together with the number of Iranian centrifuges over the last decade. The data for the Iranian nuclear program was collected from the IAEA's quarterly board reports and shows the number of installed centrifuges. Sanction data were measured in numbers of policy provisions, including initial legislation, executive actions, and extensions to these documents.

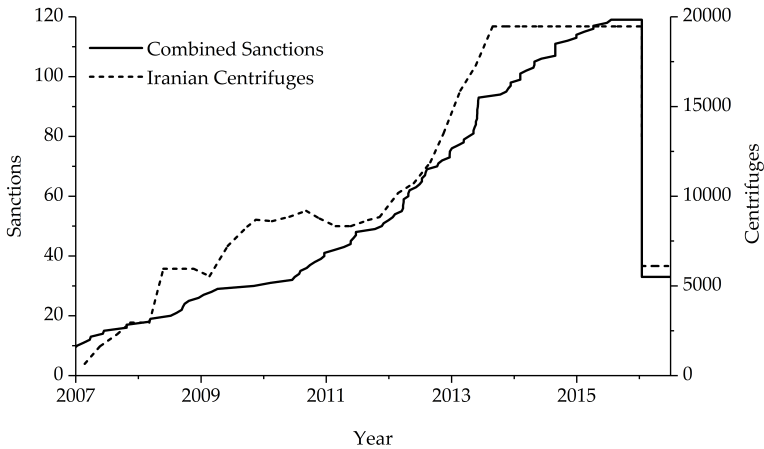


Figure 4.7.: Number of Iranian centrifuges and combined US, UNSC, and EU sanctions toward Iran for the years 2007 — 2016. Data from the IAEA and government authorities

The data show an ongoing escalation on both sides with an increase in sanctions and installed centrifuges. It seems that the pressure increased to such an extent that it became untenable and urged the parties to find a way to negotiate. In 2013, a freeze of the escalation was agreed upon to facilitate the negotiations, and at the end of 2015, an exit strategy was found. The parties finally agreed on levels of sanctions and centrifuges, which are acceptable to both sides and which are similar to the levels in

2006.

The data regarding enriched  $UF_6$  show a steady increase of production and stockpiles from both categories of up to 5% enriched and up to 20% enriched uranium. The data reveal that the production of up to 20% enriched  $UF_6$  stopped in 2014 and that the stockpile was reduced to zero. This happened as part of the confidence building measures for the negotiation of a comprehensive deal. The production and stockpile of up to 5% enriched  $UF_6$ , however, continued until implementation of the JCPoA. After implementation day, Iran drastically reduced its stock of enriched  $UF_6$ , remaining strictly under the agreed 300 kg. Figure 4.8. illustrates this development for the two enrichment categories, it shows the same data as Figure 4.4 and further includes the development after the implementation of the JCPoA.

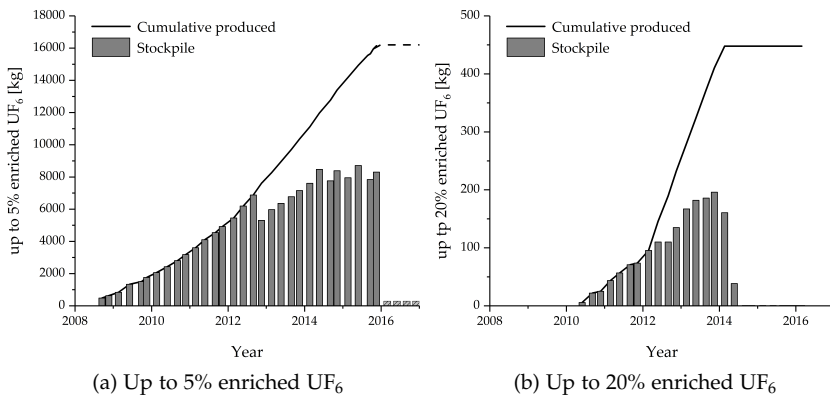


Figure 4.8.: Production and stockpile of enriched  $UF_6$  based on data from the IAEA. After the JCPoA was in place, the IAEA did not publish exact data of about up to 5% enriched  $UF_6$  but stated that the stockpile remained under the agreed 300 kg.

The role of international sanctions can be seen as an important factor in reaching a negotiated agreement. However, at the same time, Iran also increased its pressure and thereby its leverage for negotiation. A continuous escalation took part, which increased the need for a negotiation

solution. This escalation was adverse for both parties, who would likely have had a better solution if they could have agreed earlier. However, it seems that, at that time, a solution was not yet possible. Perception changed only slowly with newly elected presidents in power in both countries and the deteriorating stability in the Middle East. This finally led to a willingness to negotiate, at least in part also because of a steadily increasing pressure to find a solution.

## 4.2. Simulation Model

This section discusses the dynamic simulation model, which was introduced in Section 3.2. *Simulation Model* on page 22, with regard to the case of the Iran nuclear dispute. Even though the simulation model is abstractly formulated and studies a generic conflict involving the use of sanctions, it can also be used to illustrate and analyze the patterns and dynamics in the specific case of the interaction between US and Iran. The case analysis can help to indicate how to set the model parameters, and the results of such a simulation can be compared to the real-world observations. This analysis can help to verify the capability of the model in representing occurring patterns and provide insights in the underlying mechanisms of the case.

### 4.2.1. Simulation Model of the Iran Nuclear Dispute

The parameters for the model are set according to the initial situation. Table 4.1. lists the values for the model parameters. The sender is defined as the US and the target as Iran.<sup>18</sup> The variable  $s$  represents the number of sanctions issued by the US, and the variable  $t$  represents the number of centrifuges installed by Iran. The general model parameters are kept the same. The simulation runs over 25 rounds, with the levels of sanction  $s$  and topic  $t$  going from 0 to 1 in steps of 0.1 each. Furthermore, both initial values of  $s_0$  and  $t_0$  are set to zero, representing the beginning of the confrontation, where no nuclear-related sanctions were issued and no centrifuges were installed.

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<sup>18</sup>It is also possible to look at the sender in terms of a group of sanctioners such as the combination of the US, the EU, and the UNSC. This would require slight adjustments but would lead to similar results.

Table 4.1.: Model parameters for the simulation of the Iran nuclear dispute

Domain	Variable	Description	Value
General model parameters	$r$	Number of rounds	25
	$l$	Lower limit	0
	$u$	Upper limit	1
	$s_0$	Initial sanction value	0
	$t_0$	Initial topic value	0
	$\Delta_s$	Value of sanction change	0.1
	$\Delta_t$	Value of topic change	0.1
Utility function	$\omega_s^{US}$	US utility weight of sanctions	0.25
	$\omega_t^{US}$	US utility weight of topic	1
	$\omega_s^{IR}$	Iran utility weight of sanctions	1
	$\omega_t^{IR}$	Iran utility weight of topic	0.75
Beliefs	$\tau_0^{US}$	Initial US threshold value (expected by Iran)	0.25
	$\tau_0^{IR}$	Initial Iran threshold value (expected by US)	0
	$\sigma^{US}$	Security level US (expected by Iran)	0.05
	$\sigma^{IR}$	Security level Iran (expected by US)	0.05
Opposing	$o^{US}$	US opposing factor	0.25
	$o^{IR}$	Iran opposing factor	0.25

The utility weights define the influences of sanctions and centrifuges on the two parties. The US utility weight of sanctions  $\omega_s^{US}$  describes the amount of negative impact of the sanctions on the US. It is defined at a relatively low value of 0.25 because the economic relations with Iran are already limited and not of high importance for the US. The US utility weight of the topic  $\omega_t^{US}$  describes the amount of negative impact of the Iranian enrichment activities on the US. This value is set at the maximum because the US is strongly against a nuclearization of Iran. The Iranian utility weight of sanctions  $\omega_s^{IR}$  describes how much the sanctions hurt Iran. It is also set at the maximum, because they were rather intensive and also affected the relations with other countries. The Iranian utility weight of topic  $\omega_t^{IR}$  describes the importance of nuclear activities for Iran. It is set at 0.75 to represent a relative high priority and account for the conviction that Iran should be allowed to pursue nuclear activities for civil purposes.

The beliefs describe the assumptions of the parties, that is, how the other side will react. The US threshold value  $\tau_0^{US}$  reflects the initial beliefs of Iran at which level of centrifuges the US would start to sanction. It is set at

0.25 because Iran was initially not afraid of being sanctioned and believed that it could at least install some centrifuges without fearing consequences. The security US level  $\sigma^{US}$  describes how fast the US is expected to change its strategy from increasing sanctions to decreasing sanctions. It is set to 0.05, defining a relatively sharp change in strategy, when complying with their demand. The Iran threshold value  $\tau_0^{IR}$  describes the initial belief of the US at which level of sanctions Iran would start to comply. It is set at 0 because the US expected its sanctions to work and believed that Iran would comply. The security Iran level  $\sigma^{IR}$  describes how fast Iran is expected to change its strategy from increasing to decreasing of centrifuges. It is set at 0.05, defining a relatively sharp change in strategy.

The ideological component of the conflict is represented through the opposing factors. Both the US opposing factor  $o^{US}$  and the Iranian opposing factor  $o^{IR}$  are set to 0.25, which defines a relatively high emotionality of the conflict that represents the historical difficulties between the two parties.

#### 4.2.2. Analysis and Insights

The defined model specifications can be used to simulate the interaction of the US and Iran. Figure 4.9. illustrates the results of this simulation. The model shows that as Iran started to increase its centrifuges, the US followed by increasing sanctions. This confrontational interaction continued and reached a point where the rate of escalation further increased. Both the US and Iran raised their variables up to the maximum. A negotiation solution became attractive only for the two sides after escalation occurred. Such a negotiated agreement could then be accepted instead of further escalation but it still contains relatively high cost for both sides.

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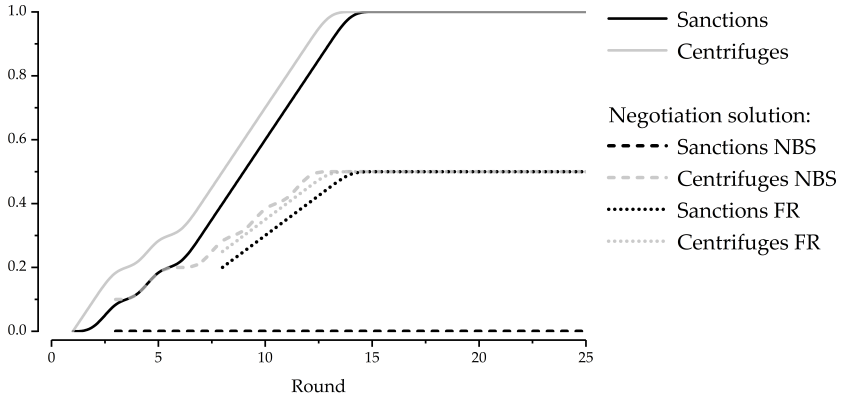


Figure 4.9.: Simulation of the Iran and US interaction with model parameters  $s_0 = t_0 = 0$ ,  $\tau_0^{US} = \tau_0^{IR} = 0.25$ ,  $\sigma_0^{US} = \sigma_0^{IR} = 0.05$ ,  $\omega_s^{US} = \omega_t^{IR} = 0.75$ ,  $\omega_t^{US} = \omega_s^{IR} = 1$ , and  $o^{US} = o^{IR} = 0.2$

#### 4.2.2.1. Escalation

Of special interest is the appearance of escalation as observed in the simulation. Analysis of the model suggests that an important aspect that can lead to the occurrence of escalation is the dominance of inadequate information or a wrong perception about one's own influence and the other side's reaction. An example is the wrong belief that a certain level of sanctions would bring the other side to give-in, or the wrong belief that a specific misbehavior would go unpunished, which then later is shown to be untrue. This is represented in this simulation through the initial threshold values for the US and Iran, contributing to an escalation. Moreover, emotional or ideological factors play an important role in leading to an escalation as represented in the model by the opposing factors. Both the ideological importance for punishing Iran for its non compliance and the ideological reason for not giving-in to US pressure were high, which led consequently to an additional increase in conflict intensity.

The simulation results represent the pattern observed in the Iran nuclear dispute, where an escalation occurred on both sides. In the beginning, the

assessment of the other side's intentions was difficult. Sanctions probably did not strictly work as initially intended and were constantly increased. Furthermore, such factors as the difficult relation between the US and Iran, pride, and intransigence led to further intensity of the conflict.

Many factors can lead to an escalation of a conflict, not only in the model but also in the more complicated reality. Especially in the case of Iran, different reasons shaped the development of the conflict. Nevertheless, it is worthwhile to observe the similarities between the theoretical model and the case. Such factors as misperception, relative importance, and ideology contributed to an ongoing escalation.

##### **4.2.2.2. Negotiation**

A further important phenomena that can be observed in the simulation is the emergence of acceptable negotiation solutions. The model shows that, under specific conditions, an increase in conflict intensity could make a negotiated solution more attractive and lead to a mutually accepted reduction of the two conflict variables. Thereby, a solution could become acceptable that was previously out of reach.

Analysis of the Iran nuclear dispute shows that, in the end, a negotiated solution was found that reduced the conflict intensity. However, this happened only after heavy escalation on both sides, when a long-term comprehensive agreement was finally seen to be more beneficial by both sides. In this process, the introduction of confidence-building measures helped to establish the grounds for serious negotiations and allowed for a cool-down of the escalation.

It is characteristic that the agreed solution would have potentially been better if an agreement were reached earlier. This distinctive tendency can be observed in the model and in reality. However, at an earlier state, the parties could not agree on a negotiated solution and had to go through an escalation of the conflict before settling on an agreement.

The assessment of the effectiveness of economic sanctions is ambivalent. It increased the costs (notably for both sides) and forced Iran to give in. Alternatively, it boosted the escalation and thereby eventually contributed to the expansion of the Iranian nuclear program, which led to a situation where a deal became acceptable, even though a better deal was unacceptable before.

Both the case study and the computational model show that a change



in pressure leads to a change in the acceptable negotiation solution. In conclusion, the evaluation and perception of a deal depend on both its substance and the circumstances. Its assessment is, therefore, not only subjective but changes over time, depending on new developments.

## 4.3. Graph Model

### 4.3.1. Graph Model of the Iran Nuclear Dispute

The GMCR methodology, as described in Section 3.3.2 *Graph Model for Conflict Resolution* on page 63, is used to model and further analyze the conflict between the US and Iran. This model can help provide additional insights regarding the decisions of the two actors and the outcomes that occurred as a result of their interaction. More precisely, the behavior of the two actors regarding the decision to escalate or negotiate at a specific time are analyzed, where sanctions are already in place by the US and nuclear activities are being conducted by Iran.

The DMs are the US and Iran. The US had the options to negotiate, further sanction, or intervene militarily. Iran has the options to negotiate or increase its nuclear activities. For the US, negotiation means that it is willing to reduce sanctions if Iran is willing to reduce its nuclear activities. For Iran, the meaning is similar in that Iran is willing to reduce nuclear activities if the US is willing to reduce sanctions.

Every option can be in the state Y or N, where Y means that the option is taken, and N means that the option is not taken by the DM who controls it. The total of five options leads to  $2^5 = 32$  possible combinations, also referred to as states. Not all of these states are possible or likely to occur in reality. For instance, the US will not simultaneously negotiate and start a military intervention. These two options are mutually exclusive, and any state in which these options are simultaneously selected is infeasible. Further mutually exclusive options for the US are negotiate and sanction as well as sanction and military intervention. For Iran, negotiate and increasing nuclear activities is mutually exclusive. These infeasible states were removed, and 12 states remained for analysis. Table 4.2. lists the DMs, their options, and all feasible states, numbered 1 — 12. The states are listed as columns, where N indicates that the DM does not take the option, while Y indicates that the DM does take the option. State 11, for

example, is the combination of selected options, in which the US does not negotiate, does increase sanctions, and does not intervene militarily, while Iran does not negotiate and increases its nuclear activities.

Table 4.2.: Feasible states for the US-Iran graph model

DM	Option	States											
		1	2	3	4	5	6	7	8	9	10	11	12
US	Negotiate	N	Y	N	N	N	Y	N	N	N	Y	N	N
	Sanction	N	N	Y	N	N	N	Y	N	N	N	Y	N
	Military intervention	N	N	N	Y	N	N	N	Y	N	N	N	Y
Iran	Negotiate	N	N	N	N	Y	Y	Y	Y	N	N	N	N
	Increase nuclear activities	N	N	N	N	N	N	N	N	Y	Y	Y	Y

The conflict can be moved by a DM from one state to another through unilateral moves by changing the option selection (for example from N to Y or vice versa), where the option selection of the other DM remains fixed. Most moves can be reversed by the DM in the course of the interaction. However, there are irreversible moves that cannot be revoked. In this example, the selection of a military intervention is such an irreversible move that is considered in the model.

The DMs prefer the states differently. The determination of these preferences is based on in-depth analysis, as described in Section 4.1. *Case Analysis* on page 67. The preferences resulted from option prioritization, which is a method based on logical preference statements regarding the option selections, and from direct ranking. Table 4.3. lists the relative preference ranking for both DMs.

Table 4.3.: DMs' relative preferences for all feasible states

DM	Preferences
US	6 > 5 > 2 > 7 > 3 > 1 > 11 > 10 > 12 > 9 > 8 > 4
Iran	9 > 10 > 6 > 2 > 5 > 1 > 11 > 7 > 3 > 12 > 8 > 4

### 4.3.2. Stability Analysis and Insights

The analysis reveals equilibrium stabilities for eight states. States 11 and 12 fulfill the Nash equilibrium concept. States 1, 2, 3, 5, 6, 7, 8, 11, and 12 fulfill GMR. States 5, 6, 11, and 12 satisfy SEQ. States 1, 2, 3, 5, 6, 7, 8, 11, and 12 fulfill SMR. States 6 and 12 fulfill limited-move stability for  $h = [2, 10]$ . States 6 and 12 fulfill non-myopic stability. Table 4.4. lists the different stabilities for all feasible states. Not all of these states are equally stable. Where states 1, 2, 3, 5, and 7 are weakly stable, states 6, 11, and 12 show a stronger stability.

Table 4.4.: Stabilities for the feasible states

		States											
		1	2	3	4	5	6	7	8	9	10	11	12
US	Negotiate	N	Y	N	N	N	Y	N	N	N	Y	N	N
	Sanction	N	N	Y	N	N	N	Y	N	N	N	Y	N
	Military intervention	N	N	N	Y	N	N	N	Y	N	N	N	Y
Iran	Negotiate	N	N	N	N	Y	Y	Y	Y	N	N	N	N
	Increase nuclear activities	N	N	N	N	N	N	N	N	Y	Y	Y	Y
Nash												✓	✓
GMR		✓	✓	✓		✓	✓	✓				✓	✓
SEQ						✓	✓					✓	✓
SMR		✓	✓	✓		✓	✓	✓				✓	✓
$L_{2-10}$							✓						✓
NM							✓						✓

This result can be further illustrated through the visualization of moves and countermoves in graph form. Figure 4.10. shows an illustration of the model with all unilateral improvement moves for the US and Iran. For example, it shows that the states that are a Nash equilibrium (states 11 and 12) have no unilateral improvement going away from these states. This further illustrates that state 6 is a strong equilibrium, because if Iran moves from there to its improved state (state 10), the US will move to state 11, which is less preferred by Iran than state 6.

This analysis can help investigate the outcome of a conflict and discuss its possible evolution. For example, states 11 and 12 are the two most stable states. In these states, Iran increases its nuclear activities, and the US increases its sanctions or even starts a military intervention. It seems

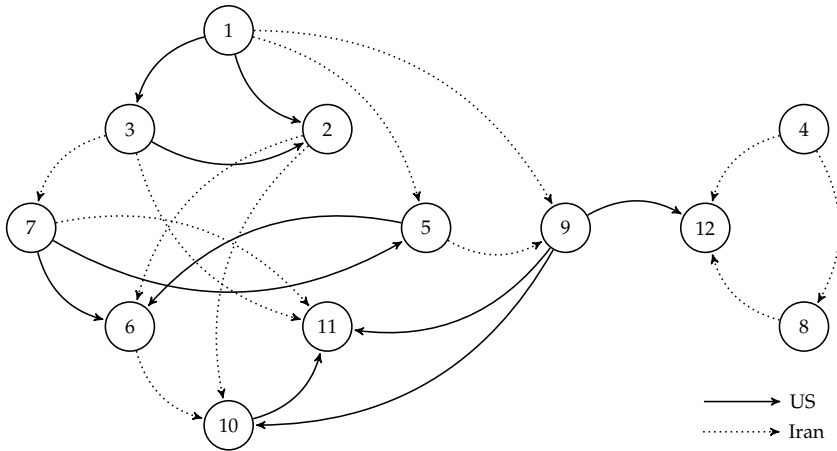


Figure 4.10.: Unilateral improvement moves

that these confrontational states are likely to occur and that, therefore, an escalation and a military conflict could emerge. Even though the actions and counteractions of the two DMs can swiftly end up in this state, the outcome is not preferred by both players. An alternative to this outcome is state 6, in which both parties agree to negotiate and reduce sanctions and nuclear activities.

Different paths lead to the stable outcome in state 6. A classical explanation could be seen in the transition from status quo (state 1), where the US increases its sanctions and, therefore, moves to state 3. Iran responds by stating its willingness to negotiate and moving to state 7. In the end, the US agrees to negotiate and move to the equilibrium state (state 6). Table 4.5. illustrates this path in which sanctions increase the willingness for negotiation.

However, other paths exist that lead to a negotiation outcome. On the side of strictly unilateral improvements, there are two additional paths: 1 - 2 - 6 and 1 - 5 - 6. The first path starts at the status quo, where the US signals its interest for negotiation, followed by Iran agreeing to negotiate. The second path is similar, with Iran first stating its interest for negotiation and the US agreeing to it. Both of these developments show an alternative to a further escalation and illustrate that the status quo is

Table 4.5.: Possible evolution of the conflict, in which an increase in sanctions causes the willingness to negotiate

DM	Option	State number			
		1	3	7	6
US	Negotiate	N	N	N	→ Y
	Sanction	N	→ Y	Y	→ N
	Military intervention	N	N	N	N
Iran	Negotiate	N	N	→ Y	Y
	Increase nuclear activities	N	N	N	N
State category		SQ	INT		EQ

undesired by both DMs, because there is already a substantial amount of sanctions and of nuclear activities.

Other realistic paths follow not only strictly utilitarian improvements but also consider further reactions by the other side. For example, one such path is 1 - 9 - 10 - 6. It starts at the status quo state, in which Iran further increases pressure through increased nuclear activities. It is followed by the US signaling its interest for negotiation, which is agreed to by Iran which, in turn, stops increasing its nuclear activities. This last move from state 10 to state 6 is not a unilateral improvement for Iran. However, if Iran decides to stay in state 10, the US has a unilateral improvement by moving to state 11, which is much worse for Iran than state 6. Furthermore, the US could move from state 9 directly to state 11. The US would choose such a bypass if the foresight and anticipation of Iran's reactions were relatively high or if a reduction of nuclear activities were seen as critical for the US. Table 4.6. illustrates this path, in which an increase in nuclear activities and the threat of sanctions yield the willingness for negotiation.

The analysis shows that, even though an escalation and even a military conflict are stable outcomes of the conflict, there exists a possibility for negotiation. Such a negotiation is preferred by both sides over a further escalation. Both an increase of sanctions and nuclear activities can lead to a negotiation, if an increase is perceived as critical for the other side.

This can also be seen in the case analysis of the Iran nuclear dispute.

4. *Iran Nuclear Dispute*

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Table 4.6.: Possible evolution of the conflict, in which an increase in nuclear activities and the threat of sanctions cause the willingness to negotiate

DM	Option	State number			
		1	9	10	6
US	Negotiate	N	N	→ Y	Y
	Sanction	N	N	N	N
	Military intervention	N	N	N	N
Iran	Negotiate	N	N	N	→ Y
	Increase nuclear activities	N	→ Y	Y	→ N
State category		SQ	INT		EQ

It shows that escalation is an unfavorable outcome that can be stopped. Furthermore, it can be seen that both the increase in sanctions and the increase in nuclear activities forced the other side to the negotiation table. But the ongoing escalation increased the costs for both sides. Therefore, a good way to steer the conflict toward an early negotiation would be through the implementation of confidence-building measures. An example is the freeze for freeze concept, in which both parties agree not to increase pressure (no increase in sanctions and no increase in nuclear activities). Such a measure increases the likelihood of mutual negotiation.

# 5. Conclusions

## 5.1. Main Findings

This dissertation develops a new perspective on sanction episodes by studying the relation between economic sanctions, conflict dynamics, and negotiation agreements. By linking these areas, it provides insights about the underlying mechanisms and the overall effects of their interaction. The main findings are:

- The coercive force of sanctions is not always effective in achieving a policy change in the target country. In the presented model, sanctions rarely led to complete concessions. More likely are partial concessions or the non-occurrence of direct concessions. These findings are in accordance with previous research that showed such effects in empirical studies (e.g., Pape, 1997; Drury, 1998; Hufbauer et al., 2009).
- A dynamic perspective on sanction episodes, which goes beyond a cause and effect consideration of coercion and concession, shows that sanctions do not only influence the ultimate decision (to give-in or not to give-in) but directly influence the dynamics of the conflict. Thereby, sanctions can particularly contribute to a conflict escalation. This finding supports previous research that found an increase in the probability of military escalation due to the use of economic sanctions (Lektzian & Sprecher, 2007).
- By intensifying the conflict, sanctions can lead to the mutual acceptance of a negotiation solution, which was out of reach before. The new circumstances of the ongoing escalation make such an agreement attractive and bring it within the range of acceptance. Therefore, the escalation can lead to the recognition that some concessions to the other side are necessary and preferred to an ongoing

escalation. This finding supports previous theoretical assumptions on escalation and the ripeness for negotiations (e.g., Zartman & Faure, 2005a).

- However, such an acceptable agreement after an escalation can be costly. It is often significantly more expensive compared to earlier agreements that were not accepted.

## 5.2. Limitations

This dissertation has certain limitations. Particularly the two methodological approaches, the formal model and the case analysis, can be critically discussed.

The constraints of the formal model emerge in parts from the general challenges of modeling. As is known, a model is a simplification of reality, intended to study only certain facets of the real world. This inevitably implies that not all aspects can be considered and incorporated. Because the selection of these factors and the way they are implemented in the model influence its results and conclusions, they have to be carefully selected and can be critically discussed. In the presented simulation model, specific assumptions could be seen as oversimplified. Examples are: First, the dyadic interacting that could be seen as neglecting other actors, which are possibly also important for the conflict. Second, the incremental changes of the sanction and the topic variable, which could be seen as a simplification over a completely free determination of these variables by the actors. Third, the reduction of the negotiation process to the acceptance of a negotiation solution. All these limitations are simplifications of reality and could be implemented in more detail. However, such possible expansions of the model often lead to an increase in complexity without adding additional value to the analysis and insights. Therefore, it always has to be evaluated, which extensions contribute to an increase in exploratory power of the model. The design and extension of the model have to be chosen in such a way that they contribute to study the questions of interest.

The constraints of the case analysis are on the one hand due to general difficulties and on the other hand case-specific challenges. First, there is the general difficulty of generalizability. A case analysis studies a unique



instance for an understanding of its specific processes. Therefore, this does not necessarily lead to generally applicable conclusions. Second, there is further the general challenge of handling complexity. When analyzing a case, boundaries have to be drawn and it is never possible to consider all aspects. These boundaries could be drawn differently and it would often be desirable to enlarge them. However, an extension can go beyond the scope of analysis. Therefore, the considered perspective has to be selected in such a way that it allows to study the aspects of interest. Third, there are case-specific challenges. There is always the difficulty of information and data availability. In the presented case it can for example be argued that conflict intensity could be measured differently. The number of centrifuges is only one aspect of advancement in a nuclear program and the number of sanctions provisions does not necessarily show the intensity of a sanction regime. However, both of these measures have to be evaluated in a broader analysis of the case, where it shows that they may not give a perfect representation of conflict intensity but still provide valuable insights.

Although formal models and case analyses inevitably have limitations, the combination of these approaches can contribute to overcome some of these weaknesses. A formal model can help to structure the case analysis and focus on the key issues where as a case analysis provides an understanding of key elements and supports the construction of the model. By combining these two perspectives one can, therefore, strengthen the analysis and contribute to more realistic results.

### **5.3. Future Research**

This dissertation opens up the field for new research by combining the areas of economic sanctions, conflict dynamics, and negotiation research. Further investigation would be possible in different areas of the presented analysis:

Specifically, it would be valuable to expand the presented model to even better represent reality and to include additional factors. Examples for an extension of the simulation model can be seen in the consideration of multiple actors or in more flexible sanction choices by the sender. Moreover, it would be interesting to include a more extensive representation of the negotiation process which goes beyond the acceptance of a

negotiated solution. Such an extensive representation of the negotiation process could help to further understand how pressure can influence the negotiation.

Furthermore, additional cases of sanction and negotiation could be considered and analyzed with respect to the introduced model. Examples for nuclear related disputes could be the case of the Democratic People's Republic of Korea or the case of Libya. Additionally, non nuclear related cases could be analyzed. This could help to generate a more detailed understanding of the underlying mechanisms, reveal similarities and differences, and increase transferability of its insights.

In addition, it would be worthwhile to further verify the results from this dissertation empirically. The presented model postulates relevant premises and it would be valuable to additionally test them. To do this, there is a need for data from many different sanction and negotiation cases. This data must include measures of conflict intensity and must further have a high resolution on the temporal dimension to verify the assumptions with regard to conflict dynamics. Currently, little data are available that consider such a high-resoluted time scale, but such a database could strengthen the combination of conflict and negotiation analysis.

## 5.4. Policy Implications

The findings of this dissertation can have potential implications for policy makers. Sanctions are a widely used policy tool with a continually increasing range of applications. When evaluating the implementation of sanctions in an international dispute, there are several aspects resulting from this analysis that should be considered.<sup>19</sup>

- This study confirms that the use of sanctions can lead to a substantial escalation of the conflict. Besides a rise in costs for both sides, such an escalation also increases the expenses for a negotiation settlement.

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<sup>19</sup>These insights could particularly be relevant with regard to other nuclear related disputes such as the currently unresolved conflict with the Democratic People's Republic of Korea.

- The results show that it would often be beneficial to start negotiations early. Therefore it is important to find strategies that can overcome the escalation trap, which emerges as costs are relatively low in the beginning and beliefs are dominant that the other side could be coerced to give-in.
- The analysis implies that sanctions can be seen as a tool to bring the other side to the negotiation table. The results show that the use of sanctions can lead to a mutually accepted agreement. However, this is related to increased costs. Such an agreement is often achieved only after conflict escalation and therefore more expensive than agreements that were previously dismissed.

It remains an important challenge to transfer these findings from ex-post analyses towards ex-ante consideration in conflict situations and policy implementation. From an overall perspective, it would generally be better to skip the escalation process and start negotiations early on. But this insight is often not realized in the present situation and the mechanisms that lead to conflict escalation are only recognized in retrospective.

All in all, it remains a challenge to balance the use of sanctions. On the one hand, they increase costs for both sides, bear the risk for dangerous escalation, and make a settlement more expensive. On the other hand, they help to bring the parties to the negotiation table and can make an agreement acceptable that was out of reach before even if it is inferior to earlier ones.



# **A. Appendices**

## **A.1. Iran Nuclear Program Database**

The Iran Nuclear Program Database lists the information about the Iranian nuclear program and its development. It provides a detailed overview of the number of centrifuges which were installed as well as operated at the different nuclear facilities. Furthermore, it lists the production as well as stockpile of enriched Uranium. All information is collected from IAEA Reports.

Table A.1.: Iran nuclear program database collected from IAEA sources

Date	Centrifuges total	Centrifuges operating (op)	IR-1	IR-2	Natanz IR-1	Natanz IR-1 op	Natanz PFEP IR-1 op	Natanz IR-2	Natanz IR-2 op	Fordow IR-1	Fordow IR-1 op	Produced $\leq$ 5% enri [kg]	Stockpile $\leq$ 5% enri [kg]	Produced $\leq$ 20% enri [kg]	Stockpile $\leq$ 20% enri [kg]
22.02.2007	656	0	656	0	656	0	0	0	0	0	0	-	-	-	-
23.05.2007	1 640	1 312	1 640	0	1 640	1 312	0	0	0	0	0	-	-	-	-
30.08.2007	2 296	1 968	2 296	0	2 296	1 968	0	0	0	0	0	-	-	-	-
15.11.2007	2 952	2 952	2 952	0	2 952	2 952	0	0	0	0	0	-	-	-	-
05.03.2008	2 952	2 952	2 952	0	2 952	2 952	0	0	0	0	0	-	-	-	-
26.05.2008	5 952	3 328	5 952	0	5 952	3 328	0	0	0	0	0	-	-	-	-
15.09.2008	5 952	3 820	5 952	0	5 952	3 820	0	0	0	0	0	480	480	-	-
19.11.2008	5 952	3 820	5 952	0	5 952	3 820	0	0	0	0	0	630	630	-	-
19.02.2009	5 537	3 936	5 537	0	5 537	3 936	0	0	0	0	0	839	839	-	-
05.06.2009	7 221	4 920	7 221	0	7 221	4 920	0	0	0	0	0	1339	1339	-	-
28.09.2009	8 308	4 592	8 308	0	8 308	4 592	0	0	0	0	0	1508	1508	-	-
16.11.2009	8 692	3 936	8 692	0	8 692	3 936	0	0	0	0	0	1763	1763	-	-
18.02.2010	8 610	3 772	8 610	0	8 610	3 772	0	0	0	0	0	2065	2065	-	-
31.05.2010	8 856	4 264	8 856	0	8 856	3 936	328	0	0	0	0	2427	2427	5.7	5.7
06.09.2010	9 184	4 100	9 184	0	8 856	3 772	328	0	0	0	0	2803	2803	22	22
23.11.2010	8 754	5 144	8 754	0	8 426	4 816	328	0	0	0	0	3183	3183	25.1	25.1
25.02.2011	8 328	5 512	8 328	0	8 000	5 184	328	0	0	0	0	3606	3606	43.6	43.6
24.05.2011	8 328	6 188	8 328	0	8 000	5 860	328	0	0	0	0	4105	4105	56.7	56.7
02.09.2011	8 676	6 188	8 676	0	8 000	5 860	328	0	0	348	0	4543	4543	70.8	70.8
08.11.2011	8 840	6 536	8 840	0	8 000	6 208	328	0	0	512	0	4922	4922	73.7	73.7
24.02.2012	10 180	9 852	10 180	0	9 156	8 828	328	0	0	696	696	5451	5451	95.4	95.4
25.05.2012	10 722	9 852	10 722	0	9 330	8 828	328	0	0	1 064	696	6197	6197	145.6	110.1
30.08.2012	11 891	10 180	11 891	0	9 423	9 156	328	0	0	2 140	696	6876	6876	189.4	91.4
16.11.2012	13 526	10 180	13 526	0	10 414	9 156	328	0	0	2 784	696	7611	5303	232.8	134.9
21.02.2013	15 887	10 014	15 707	180	12 669	8 990	328	180	0	2 710	696	8271	5974	280	167
22.05.2013	17 282	10 014	16 593	689	13 555	8 990	328	689	0	2 710	696	8960	6357	324	182

Centrifuges total: total number of installed centrifuges, Centrifuges operating: Number of centrifuges operating and fed with  $UF_6$ , IR-1: Number of Installed centrifuges of the type IR-1, IR-2: Number of Installed centrifuges of the type IR-2, Natanz IR-1: Number of installed IR-1 centrifuges in Natanz, Natanz IR-1 op: Number of operating IR-1 centrifuges in Natanz, Natanz PFEP IR-1 op: Number of operating IR-1 centrifuges in the Natanz Pilot Fuel Enrichment Plant, Natanz IR-2: Number of installed IR-2 centrifuges in Natanz, Natanz IR-2 op: Number of operating IR-2 centrifuges in Natanz, Fordow IR-1: Number of installed IR-1 centrifuges in Fordow, Fordow IR-1 op: Number of operating IR-1 centrifuges in Fordow, Produced  $\leq$  5% enri: Produced up to 5% enriched Uranium (cumulative), Stockpile  $\leq$  5% enri: Stockpile of up to 5% enriched Uranium, Produced  $\leq$  20% enri: Produced up to 20% enriched Uranium (cumulative), Stockpile  $\leq$  20% enri: Stockpile of up to 20% enriched Uranium

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Date	Centrifuges total	Centrifuges operating (op)	IR-1	IR-2	Natanz IR-1	Natanz IR-1 op	Natanz PFEP IR-1 op	Natanz IR-2	Natanz IR-2 op	Fordow IR-1	Fordow IR-1 op	Produced ≤ 5% enri [kg]	Stockpile ≤ 5% enri [kg]	Produced ≤ 20% enri [kg]	Stockpile ≤ 20% enri [kg]
28.08.2013	19 462	10 180	18 454	1 008	15 416	9 156	328	1 008	0	2 710	696	9704	6774	372.5	185.8
14.11.2013	19 466	9 824	18 458	1 008	15 420	8 800	328	1 008	0	2 710	696	10357	7154.3	410.4	196
20.02.2014	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	11111	7609	447.8	160.6
23.05.2014	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	11977	8475	447.8	38.4
05.09.2014	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	12772	7765	447.8	0.6
07.11.2014	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	13397.3	8390.3	447.8	0.6
19.02.2015	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	14174.9	7952.9	447.8	0.6
29.05.2015	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	14936.7	8714.7	447.8	0.6
27.08.2015	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	15651.4	7845.4	447.8	0.6
21.09.2015	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	-	-	447.8	0.6
20.10.2015	19 466	10 180	18 458	1 008	15 420	9 156	328	1 008	0	2 710	696	-	-	447.8	0.6
18.11.2015	14 936	-	14 088	848	11 308	-	328	848	0	2 452	-	16141.6	8305.6	447.8	0.6
16.01.2016	6 104	5 060	6 104	0	5 060	5 060	0	0	0	1 044	0	-	<300	447.8	0.6
26.02.2016	6 104	5 060	6 104	0	5 060	5 060	0	0	0	1 044	0	-	<300	447.8	0.6

Centrifuges total: total number of installed centrifuges, Centrifuges operating: Number of centrifuges operating and fed with UF<sub>6</sub>, IR-1: Number of Installed centrifuges of the type IR-1, IR-2: Number of Installed centrifuges of the type IR-2, Natanz IR-1: Number of installed IR-1 centrifuges in Natanz, Natanz IR-1 op: Number of operating IR-1 centrifuges in Natanz, Natanz PFEP IR-1 op: Number of operating IR-1 centrifuges in the Natanz Pilot Fuel Enrichment Plant, Natanz IR-2: Number of installed IR-2 centrifuges in Natanz, Natanz IR-2 op: Number of operating IR-2 centrifuges in Natanz, Fordow IR-1: Number of installed IR-1 centrifuges in Fordow, Fordow IR-1 op: Number of operating IR-1 centrifuges in Fordo, Produced ≤ 5% enri: Produced up to 5% enriched Uranium (cumulative), Stockpile ≤ 5% enri: Stockpile of up to 5% enriched Uranium, Produced ≤ 20% enri: Produced up to 20% enriched Uranium (cumulative), Stockpile ≤ 20% enri: Stockpile of up to 20% enriched Uranium

## A.2. Iran Sanction Database

The Iran Sanction Database lists the sanction provisions of the US, the EU, and the UNSC against Iran. It provides an overview of initial documents as well as sanction extensions. Furthermore, it indicates the type of sanctions and states if the sanctions were lifted after the JCPoA. All information is collected from public sources from the US, the EU, and the UN.

Table A.2.: Iran sanction database collected from public sources

Name	Ext	Sender	Date	F	M	X	O	N	T	R	A
Executive Order 12957	0	US	15.03.1995	0	0	0	1	0	0	0	0
Executive Order 12959	0	US	06.05.1995	0	1	1	0	0	0	0	0
Iran and Libya Sanctions Act	0	US	05.08.1996	1	0	0	1	0	0	0	1
Executive Order 13224	0	US	23.09.2001	1	0	0	0	0	1	0	1
Executive Order 13382	0	US	28.06.2005	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	04.01.2006	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	18.07.2006	1	0	0	0	0	0	0	1
U.N.S.C. Resolution 1696	0	UNSC	31.07.2006	0	0	0	0	1	0	0	0
U.N.S.C. Resolution 1737	0	UNSC	23.12.2006	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	09.01.2007	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	16.02.2007	1	0	0	0	1	0	0	0
U.N.S.C. Resolution 1747	0	UNSC	24.03.2007	1	1	1	0	1	0	0	0
Executive Order 13382	1	US	30.03.2007	1	0	0	0	1	0	0	1
Executive Order 13382	1	US	08.06.2007	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	15.06.2007	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	25.10.2007	1	0	0	1	1	0	0	1
Executive Order 13224	1	US	25.10.2007	1	0	0	0	0	1	0	1
U.N.S.C. Resolution 1803	0	UNSC	03.03.2008	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	12.03.2008	1	0	0	0	0	0	0	0
Executive Order 13382	1	US	08.07.2008	0	1	1	0	1	0	0	0
Executive Order 13382	1	US	12.08.2008	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	10.09.2008	0	1	1	0	1	0	0	0
Executive Order 13382	1	US	17.09.2008	1	0	0	0	0	0	0	1
U.N.S.C. Resolution 1835	0	UNSC	27.09.2008	0	0	0	0	1	0	0	0
Executive Order 13382	1	US	22.10.2008	1	0	0	0	0	0	0	0
Executive Order 13382	1	US	17.12.2008	1	0	0	0	0	0	0	0
Executive Order 13224	1	US	16.01.2009	1	0	0	0	0	1	0	1
Executive Order 13382	1	US	03.03.2009	1	0	0	0	0	0	0	0
Executive Order 13382	1	US	07.04.2009	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	05.11.2009	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	10.02.2010	1	0	0	0	0	0	0	0
Executive Order 13382	1	US	16.06.2010	1	1	1	0	1	0	0	1
Comprehensive Iran Sanctions, Accountability, and Divestment Act	1	US	01.07.2010	1	0	0	1	0	0	0	1
Council Decision 2010/413/CFSP	0	EU	27.07.2010	1	1	1	1	1	0	0	1
Executive Order 13224	1	US	03.08.2010	1	0	0	0	0	1	0	1

Ext: Extension to existing sanction, F: Financial sanction, M: Import sanction, X: Export sanction, O: Petroleum sanction, N: Related to nuclear, T: Related to terrorism, R: Sanction relief, A: In place after the implementation day of the JCPoA

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Name	Ext	Sender	Date	F	M	X	O	N	T	R	A
U.N.S.C. Resolution 1929	0	UNSC	09.09.2010	0	1	1	0	1	0	0	0
Executive Order 13553	0	US	29.09.2010	1	0	0	0	0	0	0	1
Council Decision 2010/413/CFSP: Council Decision 2010/644/CFSP	1	EU	27.10.2010	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	30.11.2010	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	21.12.2010	1	0	0	0	1	0	0	0
Executive Order 13224	1	US	21.12.2010	1	0	0	0	0	1	0	1
Executive Order 13382	1	US	17.02.2011	1	0	0	0	1	0	0	0
Council Decision 2011/235/CFSP	0	EU	14.04.2011	1	0	0	0	0	0	0	1
Executive Order 13574	1	US	23.05.2011	1	0	0	1	0	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2011/299/CFSP	1	EU	24.05.2011	1	0	0	0	1	0	0	0
U.N.S.C. Resolution 1984	1	UNSC	09.06.2011	0	0	0	0	1	0	0	0
Executive Order 13382	1	US	23.06.2011	1	1	1	0	1	0	0	0
Executive Order 13224	1	US	23.06.2011	1	0	0	0	0	1	0	1
Council Decision 2011/235/CFSP: Council Implementing Decision 2011/670	1	EU	12.10.2011	1	0	0	0	0	0	0	1
Executive Order 13590	0	US	21.11.2011	1	0	0	1	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2011/783/CFSP	1	EU	02.12.2011	1	0	0	0	1	0	0	0
Section 1245 of the National Defense Authorization Act for fiscal year 2012	0	US	31.12.2011	1	1	1	1	0	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2012/35/CFSP	1	EU	24.01.2012	1	1	1	1	1	0	0	0
Executive Order 13599	0	US	06.02.2012	1	1	1	1	0	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2012/152/CFSP	1	EU	16.03.2012	1	0	0	0	1	0	0	0
Council Decision 2011/235/CFSP: Council Decision 2012/168/CFSP	1	EU	24.03.2012	1	1	0	0	0	0	0	1
Council Decision 2010/413/CFSP: Council Decision 2012/169/CFSP	1	EU	24.03.2012	1	0	0	0	1	0	0	0
Executive Order 13224	1	US	27.03.2012	1	0	0	0	0	1	0	1
Executive Order 13382	1	US	28.03.2012	1	0	0	0	1	0	0	1
Executive Order 13606	0	US	23.04.2012	1	0	0	0	0	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2012/205/CFSP	1	EU	24.04.2012	1	0	0	0	1	0	0	0
Executive Order 13608	0	US	01.05.2012	1	1	1	1	1	0	0	0
U.N.S.C. Resolution 2049	1	UNSC	07.06.2012	0	0	0	0	1	0	0	0
Section 1245 of the National Defense Authorization Act for fiscal year 2012	1	US	28.06.2012	1	0	0	1	0	0	0	0
Executive Order 13382	1	US	12.07.2012	1	1	1	0	1	0	0	0
Executive Order 13599	1	US	12.07.2012	1	0	0	1	0	0	0	0
Executive Order 13622	1	US	30.07.2012	1	0	0	1	0	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2012/457/CFSP	1	EU	03.08.2012	1	0	0	0	1	0	0	0
Iran Threat Reduction and Syria Human Rights Act of 2012 (H.R. 1905)	0	US	10.08.2012	1	1	1	1	0	0	0	1
Executive Order 13628	1	US	09.10.2012	1	0	0	1	0	0	0	1
Council Decision 2010/413/CFSP: Council Decision 2012/635/CFSP	1	EU	16.10.2012	1	1	1	1	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2012/687/CFSP	1	EU	07.11.2012	1	0	0	0	1	0	0	0

Ext: Extension to existing sanction, F: Financial sanction, M: Import sanction, X: Export sanction, O: Petroleum sanction, N: Related to nuclear, T: Related to terrorism, R: Sanction relief, A: In place after the implementation day of the JCPOA

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## A. Appendices

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Name	Ext	Sender	Date	F	M	X	O	N	T	R	A
Council Decision 2011/235/CFSP: Council Decision 2012/810/CFSP	1	EU	21.12.2012	1	0	0	0	0	0	0	1
Executive Order 13382	1	US	21.12.2012	1	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2012/829/CFSP	1	EU	22.12.2012	1	0	0	0	1	0	0	0
The National Defense Authorization Act for Fiscal Year 2013	1	US	02.01.2013	1	1	1	1	1	0	0	0
Executive Order 13628	1	US	06.02.2013	1	0	0	1	0	0	0	1
Council Decision 2011/235/CFSP: Council Decision 2013/124/CFSP	1	EU	12.03.2013	1	0	0	0	0	0	0	1
Executive Order 13599	1	US	14.03.2013	1	1	1	1	0	0	0	0
Executive Order 13382	1	US	11.04.2013	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	09.05.2013	1	0	0	0	1	0	0	0
Executive Order 13599	1	US	09.05.2013	1	0	0	1	0	0	0	0
Executive Order 13382	1	US	15.05.2013	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	23.05.2013	1	0	0	0	1	0	0	0
Executive Order 13599	1	US	23.05.2013	1	1	1	1	0	0	0	0
Executive Order 13553	1	US	30.05.2013	1	0	0	0	0	0	0	1
Executive Order 13628	1	US	30.05.2013	1	0	0	1	0	0	0	1
Executive Order 13608	1	US	31.05.2013	1	1	1	1	1	0	0	0
Executive Order 13599	1	US	31.05.2013	1	0	0	1	0	0	0	0
Executive Order 13645	0	US	03.06.2013	1	0	0	0	0	0	0	0
Executive Order 13599	1	US	04.06.2013	1	1	1	1	0	0	0	0
U.N.S.C. Resolution 2105	1	UNSC	05.06.2013	0	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2013/270/CFSP	1	EU	08.06.2013	1	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2013/497/CFSP	1	EU	12.10.2013	1	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2013/661/CFSP	1	EU	16.11.2013	1	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2013/685/CFSP	1	EU	27.11.2013	1	0	0	0	1	0	0	0
Executive Order 13645	1	US	12.12.2013	1	0	0	1	0	0	0	0
Executive Order 13382	1	US	12.12.2013	1	0	0	0	1	0	0	0
Executive Order 13608	1	US	06.02.2014	1	0	0	0	0	0	0	0
Executive Order 13382	1	US	06.02.2014	1	0	0	0	1	0	0	0
Executive Order 13224	1	US	06.02.2014	1	0	0	0	0	1	0	1
Council Decision 2011/235/CFSP: Council Decision 2014/205/CSFP	1	EU	12.03.2014	1	0	0	0	0	0	0	1
Council Decision 2010/413/CFSP: Council Decision 2014/222/CFSP	1	EU	23.04.2014	1	0	0	0	1	0	0	0
Executive Order 13382	1	US	29.04.2014	1	0	0	0	1	0	0	0
Executive Order 13645	1	US	29.04.2014	1	0	0	0	0	0	0	0
U.N.S.C. Resolution 2159	1	UNSC	09.06.2014	0	0	0	0	1	0	0	0
Executive Order 13382	1	US	29.08.2014	1	0	0	0	1	0	0	0
Executive Order 13645	1	US	29.08.2014	1	0	0	1	0	0	0	0
Executive Order 13622	1	US	29.08.2014	1	0	0	0	0	0	0	0
Executive Order 13599	1	US	29.08.2014	1	0	0	0	0	0	0	0
Executive Order 13224	1	US	29.08.2014	1	0	0	0	0	1	0	1
Council Decision 2010/413/CFSP: Council Decision 2014/776/CSFP	1	EU	08.11.2014	1	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision 2014/829/CSFP	1	EU	25.11.2014	0	0	0	0	1	0	1	0

Ext: Extension to existing sanction, F: Financial sanction, M: Import sanction, X: Export sanction, O: Petroleum sanction, N: Related to nuclear, T: Related to terrorism, R: Sanction relief, A: In place after the implementation day of the JCPoA

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Name	Ext	Sender	Date	F	M	X	O	N	T	R	A
Executive Order 13622	1	US	30.12.2014	1	0	0	0	0	0	0	0
Executive Order 13553	1	US	30.12.2014	1	0	0	0	0	0	0	1
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/236	1	EU	14.02.2015	1	0	0	0	1	0	0	0
Council Decision 2011/235/CFSP: Council Decision 2015/555/CSFP	1	EU	08.04.2015	1	0	0	0	0	0	0	1
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/556	1	EU	08.04.2015	1	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/1008	1	EU	26.06.2015	1	0	0	0	1	0	0	0
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/1050	1	EU	01.07.2015	0	0	0	0	1	0	1	0
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/1099	1	EU	08.07.2015	0	0	0	0	1	0	1	0
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/1130	1	EU	11.07.2015	0	0	0	0	1	0	1	0
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/1148	1	EU	14.07.2015	0	0	0	0	1	0	1	0
U.N.S.C. Resolution 2231	0	UNSC	20.07.2015	0	0	0	0	1	0	0	1
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/1336	1	EU	01.08.2015	0	0	0	0	1	0	1	0
Council Decision 2010/413/CFSP: Council Decision (CFSP) 2015/1337	1	EU	01.08.2015	0	0	0	0	1	0	1	0

Ext: Extension to existing sanction, F: Financial sanction, M: Import sanction, X: Export sanction, O: Petroleum sanction, N: Related to nuclear, T: Related to terrorism, R: Sanction relief, A: In place after the implementation day of the JCPOA

### A.3. Simulation Model Code

This appendix provides the code of the presented sequential repeated computational model. It is programmed in R and provides the basis for the simulations of this dissertation.

```
1 #####
2 #           Computational Sanction Model           #
3 #           Tobias W. Langenegger                 #
4 #           2018                                 #
5 #####
6
7
8 ##### Inputs #####
9
10 s <- 0 # initial value for sanction [0,1]
11
12 t <- 0 # initial value for topic [0,1]
13
14 sch <- 0.1 # sanction change [0,1]
15
16 tch <- 0.1 # topic change [0,1]
17
18 ths <- 0.25 # threshold sender (expected by target) [0,1]
19
20 secs <- 0.05 # security level sender (expected by target) [0,1]
21
22 tht <- 0.25 # threshold target (expected by sender) [0,1]
23
24 sect <- 0.05 # security level target (expected by sender) [0,1]
25
26 wss <- 1 # Senders utility weight of sanctions [0,1]
27 wst <- 1 # Senders utility weight of topic [0,1]
28 wts <- 1 # Targets utility weight of sanctions [0,1]
29 wtt <- 1 # Targets utility weight of topic [0,1]
30
31 opposingfactors <- 0.25 # [0,1]
32 opposingfactort <- 0.25 # [0,1]
33
34 rounds <- 50 # number of rounds
35
36 u <- 1 # upper limit
37
38 l <- 0 # lower limit
39
40 x <- 1 # initial round
41
42
```

```
43 ##### Utilityfunctions #####
44
45 us <- function(s,t) {
46   utility=(-wss*s-wst*t)
47   return(utility)
48 } # Utilityfunction Sender
49
50 ut <- function(s,t) {
51   utility=(-wts*s-wtt*t)
52   return(utility)
53 } # Utilityfunction Target
54
55 ##### Expectations #####
56
57
58 rsx <- function(s,t,ths){
59   if(t>ths){
60     sxn=s+sch;
61   }else{
62     if(t<=ths && t>=(ths-secs)){
63       sxn=s;
64     }else{
65       if(t<(ths-secs)){
66         sxn=s-sch;
67       }
68     }
69   }
70   if(sxn>u){
71     sxn=u;
72   }else{
73     if(sxn<1){
74       sxn=1
75     }
76   }
77   return(sxn)
78 } # expected sanction change function of T about s
79
80 rtx <- function(s,t,tht){
81   if(s>tht){
82     txn=t-tch;
83   }else{
84     if(s<=tht && s>=(tht-sect)){
85       txn=t;
86     }else{
87       if(s<(tht-sect)){
88         txn=t+tch;
89       }
90     }
91   }
92   if(txn>u){
93     txn=u;
94   }else{
95     if(txn<1){
96       txn=1
97     }
98   }
99 }
```

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---

```
99     return(txn)
100 } # expected topic change function of S about t
101
102
103 ##### Opposing #####
104
105 oppot <- function(s,ss){
106   if(ss-s>0){
107     opposing=sqrt(ss)*opposingfactort;
108   }else{
109     opposing=0
110   }
111   return(opposing)
112 }
113
114 oppos <- function(t,tt){
115   if(tt-t>0){
116     opposing=tt^2*opposingfactors;
117   }else{
118     opposing=0
119   }
120   return(opposing)
121 }
122
123
124 ##### Reaction / Optimization #####
125
126 rs <- function(s,t,tht,oppos){
127   if(us(s+sch,rtx(s+sch,t,tht))+oppos>us(s,rtx(s,t,tht))){
128     sn=s+sch;
129   }else{
130     if(us(s-sch,rtx(s-sch,t,tht))>us(s,rtx(s,t,tht))){
131       sn=s-sch;
132     }else{
133       sn=s;
134     }
135   }
136   if(sn>=u){
137     sn=u;
138   }
139   if(sn<=l){
140     sn=l;
141   }
142   return(sn)
143 } # Sanction change function of S (optimization)
144
145 rt <- function(s,t,ths,oppot){
146   if(ut(rsx(s,t+tch,ths),t+tch)>ut(rsx(s,t,ths),t)){
147     tn=t+tch;
148   }else{
149     if(ut(rsx(s,t-tch,ths),t-tch)-oppot>ut(rsx(s,t,ths),t)){
150       tn=t-tch;
151     }else{
152       tn=t;
153     }
154   }
155 }
```

```

155     if(tn>=u){
156         tn=u;
157     }
158     if(tn<=l){
159         tn=l;
160     }
161     return(tn)
162 } # Topic change function of T (optimization)
163
164
165 ##### Learning #####
166
167 thschange <- function(ths,s,ss,t){
168     if(s==ss && ss==u){
169         thsn=ths+0.5*tch;
170     }else{
171         if(s==ss && ss==l){
172             thsn=ths-0.5*tch;
173         }else{
174             if(s==ss && t>ths){
175                 thsn=t+(secs/2);
176             }else{
177                 if(s==ss && t<ths-secs){
178                     thsn=t+(secs/2);
179                 }else{if(s<ss && t<=ths){
180                     thsn=t-tch;
181                 }else{
182                     if(s>ss && t>=ths-secs){
183                         thsn=t+(1.1*secs);
184                     }else{
185                         thsn=ths;
186                     }
187                 }
188             }
189         }
190     }
191 }
192 if(thsn>=u){
193     thsn=u;
194 }
195 if(thsn<=l){
196     thsn=l;
197 }
198 return(thsn)
199 } # Threshold Sender update function (learingn of Target)
200
201
202 thtchange <- function(tht,s,t,tt){
203     if(t==tt && t==u){
204         thtn=tht+0.5*sch;
205     }else{
206         if(t==tt && t==l){
207             thtn=tht-0.5*sch;
208         }else{
209             if(t==tt && s>tht){
210                 thtn=s+(sect/2);

```

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---

```
211         }else{
212             if(t==tt && s<tht-sect){
213                 thtn=s+(sect/2);
214             }else{
215                 if(t<tt && s>=tht-sect){
216                     thtn=s+(1.1*sect);
217                 }else{
218                     if(t>tt && s<=tht){
219                         thtn=s-sch;
220                     }else{
221                         thtn=tht;
222                     }
223                 }
224             }
225         }
226     }
227 }
228 if(thtn>=u){
229     thtn=u;
230 }
231 if(thtn<=l){
232     thtn=l;
233 }
234 return(thtn)
235 } # Threshold Target update function (learingn of Sender)
236
237
238 ##### Negotiation #####
239
240 # Nash Bargaining Solution #
241
242 sp <- seq(l,u,len=(u-l)/sch+1) #possible s
243 tp <- seq(l,u,len=(u-l)/tch+1) #possible t
244
245 negos <- function(sn,tn,x){
246     utilitymultiplication <- function(s,t)(us(s,t)-us(sn,tn))*(ut(s,t)
247         )-ut(sn,tn))
248     utilitymulti <- round(outer(0,tp,FUN=utilitymultiplication),
249         digits=10);
250     max <- which(utilitymulti == max(utilitymulti), arr.ind = TRUE);
251     negos=sp[max[1,1]];
252     return(negos)
253 }
254
255 negot <- function(sn,tn,x){
256     utilitymultiplication <- function(s,t)(us(s,t)-us(sn,tn))*(ut(s,t)
257         )-ut(sn,tn))
258     utilitymulti <- outer(0,tp,FUN=utilitymultiplication);
259     max <- which(utilitymulti == max(utilitymulti), arr.ind = TRUE);
260     negot=tp[max[1,2]];
261     return(negot)
262 }
263
264 # Fixed Reduction #
265
266 negos <- function(s,t,x){
```



```

264     negos=0.5*s
265     return(negos)
266 }
267 negot <- function(s,t,x){
268     negot=0.5*t
269     return(negot)
270 }
271
272 #--Comparison of Negotiation with current situation--#
273
274 nego <- function(s,t,x){
275     if(us(negos(s,t,x),negot(s,t,x))>us(s,t) && ut(negos(s,t,x),negot
276         (s,t,x))>ut(s,t)){
277         negsols=c(negos(s,t,x),negot(s,t,x));
278     }else{
279         negsols=c(NA,NA);
280     }
281     return(negsols)
282 }
283
284 ##### Execution #####
285
286 n <- 1 # initial round
287
288 sanction=s;
289
290 topic=t;
291
292 thresholdt=tht;
293
294 thresholds=ths;
295
296 utilitys=us(s,t);
297
298 utilityt=ut(s,t);
299
300 opposings=0;
301
302 opposingt=0;
303
304 negotiation=nego(s,t,n);
305
306 negous=us(negos(s,t,x),negot(s,t,x));
307
308 negout=ut(negos(s,t,x),negot(s,t,x));
309
310 while(n<rounds) {
311     sanctionnew=rs(sanction[n],topic[n],thresholdt[n],opposings[n]);
312     sanctionnew=round(sanctionnew, digits=10);
313     sanction=c(sanction, sanctionnew);
314     thresholdsnew=thschange(thresholds[n],sanction[n],sanction[n+1],
315         topic[n]);
316     thresholdsnew=round(thresholdsnew, digits=10);
317     thresholds=c(thresholds, thresholdsnew);
318     topicnew=rt(sanction[n+1],topic[n],thresholds[n+1],opposingt[n]);

```

```
318     topicnew=round(topicnew, digits=10);
319     topic=c(topic, topicnew);
320     thresholdtnew=thtchange(thresholdt[n], sanction[n], topic[n], topic[
        n+1]);
321     thresholdtnew=round(thresholdtnew, digits=10);
322     thresholdt=c(thresholdt, thresholdtnew);
323     utilitysnew=us(sanction[n+1], topic[n+1]);
324     utilityt=c(utilityt, utilitysnew);
325     utilitytnew=ut(sanction[n+1], topic[n+1]);
326     utilityt=c(utilityt, utilitytnew);
327     opposings=c(opposings, oppos(topic[n], topic[n+1]));
328     opposingt=c(opposingt, oppot(sanction[n], sanction[n+1]));
329     negotiation=c(negotiation, nego(sanction[n+1], topic[n+1], n+1));
330     negous=c(negous, us(negos(sanction[n+1], topic[n+1], n+1), negot(
        sanction[n+1], topic[n+1], n+1)));
331     negout=c(negout, ut(negos(sanction[n+1], topic[n+1], n+1), negot(
        sanction[n+1], topic[n+1], n+1)));
332     n=n+1;
333 }
```

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