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A Rational Explanation of the 2019 Dispute Between Japan and South Korea

What strategic motivations led to the 2019 Japan-South Korea dispute?

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Abstract

This thesis provides a rational analysis of the strategic motivations underlying the 2019 Japan–South Korea dispute. Utilizing game theory, the dispute is represented through various models, each highlighting different aspects and assumptions. The first model explores the strategic challenges that favor escalation and unilateral gains, leading to difficulty in resolving the conflict. In the next model Japan's actions are perceived as an implicit threat designed to shape future interactions. This necessitates credible follow-through, thereby potentially influencing South Korea's future decisions. Finally a two-level game is considered examining domestic constraints on international negotiation. The model demonstrates that actions deemed irrational at the international level can be rational when considering domestic-level payoffs. It also shows how domestic factors, under imperfect information, can contribute to the breakdown of negotiations. Additionally, the thesis introduces the the Python library StratPy that was developed in conjunction with this thesis in order to model and analyze the game-theoretical models, and was made to be especially accommodating to political scientists.

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List of Acronyms

API Application Programming Interface

GSOMIA General Security of Military Information

MECR Multilateral Export Control Regime

METI Ministry of Economics, Trade, and Infrastructure

ML Machine Learning

MOFA Ministry of Foreign Affairs

MOTIE Ministry of Trade, Industry and Energy

NE Nash Equilibrium

PBE Perfect Bayesian Equilibrium

SPE Subgame Perfect Equilibrium

Preface

I would like to extend my thanks to my supervisor Scott Gates, whose class on *Rational Choice and International Conflict* got me started on this game theoretical journey of utility functions and player strategies. A warm thank you to Sachio Konishi, Professor of Economics at Kwansei Gakuin University, for his valuable insights into Japanese economic policy making. Special thanks to the Norwegian Embassy in Tokyo and all its wonderful employees who graciously hosted me in 2022 and allowed me to gain a deeper understanding of foreign policy in practice.

Thank you to the welcoming Rust Community and Pyo3/Maturin contributers for providing thorough documentation and general assistance for integrating Rust with Python during the development of Stratpy.

I would also like to thank my sister Benedicte for proofreading. Thanks to my dog Tesla who was always willing to take me out for a study break walk. Finally I would like to thank my co-author coffee, whose contributions were both meaningful and necessary. All mistakes in this thesis are entirely my own.

But that's just a theory. A Game Theory. Thanks for reading.

Chapter 1

Introduction

1.1 Introduction

At first glance, Japan and the Republic of Korea[1] appear as natural allies. Both states are democracies with a capitalistic economic system. They are geographically close and share military alliances with the United States, confronting common security challenges from North Korea and China. From the perspective of the United States, a strong alliance between the two states would mean a stronger and more secure opposition to China. Regardless, Japanese–South Korean relations have been anything but friendly, being plagued with unresolved issues stemming from Japan's 1910-1945 annexation of Korea. Despite this, the two states have achieved significant economic cooperation, to the benefit of them both. South Korea is currently Japan's third largest trading partner after the United States and China.

In 2019, Japan decided to restrict the export of key material used in semiconductor production to South Korea citing national security concerns. This resulted in an ongoing trade dispute deteriorating relations to the lowest point since the end of the war. The result of the dispute have led to further tensions in their ongoing territorial dispute concerning the Liancourt rocks, as well as South Korea expressing their intention to leave the joint military information agreement they had with Japan. This conflict epitomizes the historical mistrust between the states, which has resulted in a seemingly sub-optimal outcome for both parties. Common explanations gravitate towards cultural and nationalistic factors, such as anti-Japanese/Korean sentiments in the respective countries. This thesis instead

[1]Henceforth referred to as South Korea and at times Korea if the context is clear.

proposes a novel approach. Utilizing game-theoretical models, I will analyze the conditions that led to this conflict, offering a rational explanation distinct from traditional cultural analyses.

In conjunction with the thesis I have developed StratPy, a Python library for Game Theory, which will be used for modeling the games representing the dispute. The library was written alongside the thesis according to its requirements, and is thus especially accommodating for uses in political science.

Furthermore, this research addresses the Western-centric bias in International Security Studies, which has historically been dominated by security issues faced by western states. This has left non-western security issues comparatively understudied. Buzan & Hansen(2009) cites "Western-centrism" as problematic for the discipline limiting the field, a point that becomes increasingly relevant with Asia's rising geopolitical significance. With the rise of China, and economic boom in the region, Asia has increasingly become an important area to study. By applying security theories to an Asian context, this thesis contributes to a more balanced and comprehensive understanding of global security dynamics. The ongoing dispute between Japan and South Korea is not only significant in its own right but also has implications for Western interests, particularly for the United States, which relies on a united front amongst its allies in the region. The deterioration of the Japan–South Korea relationship, exemplified by the dissolution of their joint military information agreement, poses challenges not just to the involved states but to the broader strategic balance in Asia. (Sakaki, 2019)

1.2 Thesis Structure

Chapter 1 introduces the topic of this thesis, the research question, and the motivations for using Game Theory as a method. The StratPy library is also introduced together with my motivations for developing it. **Chapter 2** presents a brief overview of the background to the dispute and goes on to review prior research as well as the thesis' contribution to the literature.

Next, in **Chapter 3**, I will detail the theory used in the thesis, i.e.—Game Theory—as a method as well as the assumptions made, most notably the rationality assumption. I will then document how the theory and method was implemented into the Python library, as well as the research design and methodological considerations for this thesis.

The next three chapters are the bulk of the analysis: Here I will present the formal games used to model the dispute as well as their implications. **Chapter 4** represents the game as static payoff matrices, where players move simultaneously. **Chapter 5** introduces sequential moves, modeling the game in extensive form, and introduces imperfect information. Finally, **Chapter 6** relaxes the notion of a unitary actor by modeling the constraints of domestic politics on foreign policy. This chapter uses the so called Two-Level Game to model this interaction.

Chapter 7 is the concluding chapter summarizing the findings of the thesis, and discusses possibilities for further research.

1.3 Research Question

This thesis will attempt to give a rational explanation of what strategies lead to the dispute between the states. The research question is formulated as such:

What strategic motivations led to the 2019 Japan–South Korea dispute?

In order to answer this question, I will model the dispute using formal game-theoretical models. Strategic motivation will be represented by the payoffs and available game-theoretical strategies present in the games. The key terms of Game Theory, such as 'payoffs' and 'strategies,' will be defined in the methodology section. By analyzing the payoffs and strategies we can calculate equilibrium states, thereby "solving" the game. These models will then give a representation of the dispute as is, and why the seemingly sub-optimal outcome was reached. In order to gain an accurate representation of the state's preferences, the paper will base these on the government's official statements pertaining to the dispute as well as secondary literature to ensure accuracy in the state's utility modeled in the games.

It is worth noting that the paper's aim is not to make a normative evaluation of the situation. Whether any party is justified in their actions based on any moral or legal grounds is outside the scope of the thesis. Rather the thesis wishes to analyze what motivations lead to the dispute using a rationalist framework. Adopting a rationalist framework allows for an objective analysis of the motivations behind the dispute, devoid of moral or legal judgments.

The implications of this analysis are twofold. Firstly, it contributes to a more nuanced understanding of the Japan–South Korea dispute itself. Secondly, it provides a methodological blueprint for dissecting similar conflicts, highlighting the utility and limitations of Game Theory in the domain of international relations.

1.4 Game Theory as a method

Given that we are interested in the strategic motivations that led to the dispute, Game Theory is a natural choice as a method and provides a robust framework for this type of analysis. In section 2.2 and 2.3 I detail my motivations for providing a rational explanation of the dispute. In this section I would like to address the use of Game Theory as a method. Morrow (Morrow, 1994) identifies the strengths of using Game Theory in political science in its ability to focus on strategic interaction and being able to model both actions taken and the actions outside the equilibrium path. It prompts us to think about how beliefs, goals, and social structures influence behavior, especially when individuals must account for the actions of others. By defining a game, we essentially outline a social structure, capturing decision-making rules, capabilities, and perceived choices, all of which can be altered within the game to explore different structural consequences. As with any model, there are many aspects of the case studied that are not captured. However, through modeling the case using different games with different assumption we can highlight different aspects of the case, and further our understanding in ways not necessarily produced by using other frameworks. (Hermans et al., 2014)

Additionally, Game Theory has also seen renewed interest in recent years due to its application in Machine Learning (ML). (Rezek et al., 2008) As ML is being implemented in an increasing amount of fields, its potential applications in political science is also evident. One such application can be to more accurately predict the utility and preferences of states through analyzing the wealth of data already available. Providing game theoretical frameworks in the field of political science is an important first step.

1.5 StratPy - a Game Theory Library

StratPy is an open source Python library for Game Theory, developed in conjunction with this thesis. StratPy[2]. In this section I will present a brief introduction to the library, my motivations for writing the library, and compare it with already existing libraries. StratPy allows users to easily create game-theoretical models, both in normal and extensive form. These models can then be analyzed with built-in functions, and be exported to open formats such as Graphviz (Ellson et al., 2002) using DOT or LaTex. My motivation for creating

[2] StratPy is developed and maintained in a public repository hosted on https://github.com/fredrikofstad/StratPy

this library were two-fold: To aid in analyzing and finding solution strategies to the models; and to simplify model construction as well as exporting said models to LaTex by generating *.tex* files.

The motivation for using a library at all is to provide the research with documented instructions on how to replicate the results. As such it was important to not use software with a graphical user interface but rather a software script that can be read line by line, to see all commands and arguments made. In addition to increasing the reproducibility of the research, it can also aid in finding potential errors or weaknesses, as all the calculations are readily available. Furthermore, it allows for rigorous testing, which reduces potential errors. This will be further detailed in Section 3.2.2.

There are other already established libraries for Game Theory, the two most relevant libraries being Gambit (McKelvey et al., 2022) and Nashpy (Knight, 2017). While these packages are excellent in their own right, I still chose to develop my own, as they did not quite fit my requirements. In political science it is often hard to quantify the payoffs as precisely as in economics, or in more theoretical games. As such, StratPy provides an ordinal variable class to allow for inferences on possible strategy sets to be made without having to resort to numerical values. Both Gambit and Nashpy require numerical payoffs in order for their algorithms to work. To make a library that also works in political science it was important to add a variable data structure, whose ordinal value could be set by the user.

Additionally, I wanted a library that could directly export the models into latex figures. This is important as it allows the user to make iterative changes without having to recreate the figures, and also ensures that the figure shown is the same version as the one analyzed.

The package itself is written in Rust. (Matsakis and Klock II, 2014) While Rust is a relatively new language, there are a couple strong reasons for its use. The language gives low level access to hardware and memory while still being memory-safe through its ownership system. The execution speed is therefore also comparable to other low-level languages like C. Additionally the language, unlike Python, is statically typed, ensuring most errors are found during compile time, rather than run-time. This is beneficial both during development, and to ensure that hidden errors don't arise in scarcely reached situations.

While I have now argued for the importance of statically typed languages with robust type checking, it might seem counter-intuitive that the library itself is a

Python package. There are two main reasons for this:

1. Researchers both inside and outside of academia have overwhelmingly adopted Python as their language of choice. The advantages of having no compile-time type-checking and simple syntax, is that the language is easy to learn and easy to use. To accommodate potential users of this library, only the Application Programming Interface (API) that the user interacts with, is written to be used in Python. This means that the heavy lifting and type safety is still ensured by Rust, while the Python layer is merely used to call functions from Rust. Furthermore, Python is also callable in R, another much used language for research, especially in the field of statistics and data science.

2. The other reason is due to the potential use of ML when using this library. Most well known and used libraries in ML like Google's Tensorflow (Martín Abadi et al., 2015) or Meta's PyTorch (Paszke et al., 2019) are Python packages. It is therefore beneficial to use the same language in order to allow for future integration.

Chapter 2

Background

In this chapter I will summarize the 2019 trade dispute and the events leading up to it. I will then present a literature review detailing the prior research published on this case and their results. Finally, I will discuss how this thesis fits into the literature, and what contributions this thesis will make.

2.1 Background

The Second World War marked the end of Japan's 35-year annexation of the Korean peninsula, leading to the eventual establishment of the Republic of Korea in the southern part of the peninsula in August 1948. The legacy of the colonization was contentious, creating deep-seated issues that lingered unresolved for years. It was not until the signing of the *Treaty on Basic Relations* between Japan and the Republic of Korea in 1965 that the two nations attempted to formally reconcile their tumultuous history. (Treaty on Basic Relations between Japan and the Republic of Korea, 1965) The treaty served not only to establish diplomatic relations but also to address reparations and economic cooperation, with Japan providing South Korea with $800 million in grants and soft loans as compensation for the colonial period. The Japanese government has steadfastly maintained that this treaty resolved all claims related to its colonial rule, including property and individual compensation matters.

However, this interpretation has been challenged within South Korea, particularly by the judiciary. The Supreme Court of South Korea's landmark ruling on October 30, 2018, sparked a renewed conflict over historical grievances. (Decision by South Korea's Supreme Court on October 30, 2018,

2018) The court affirmed that, while the treaty might have settled government-to-government claims, it did not waive the rights of individuals or their families to pursue reparations from Japanese firms that benefited from forced labor during the occupation. When Japanese companies such as Nippon Steel and Mitsubishi Heavy Industries were ordered to compensate Korean victims' families, it reignited historical tensions and began to manifest in economic and trade policies between the two nations.

The dispute escalated in July 2019 when Japan imposed export controls on three crucial chemical components vital for the semiconductor industry a sector at the core of South Korea's economy. The strategic importance of these materials cannot be overstated; fluorinated polyimide is essential for the production of high-performance displays, photoresists are crucial for semiconductor lithography, and hydrogen fluoride is used to clean semiconductor devices. As the world's largest producer of semiconductors, and with companies such as Samsung relying heavily on these materials for their smartphone and television production, these restrictions posed a significant risk to the South Korean economy, with Samsung alone accounting for more than 14% of South Korea's GDP. The implications of Japan's restrictions also extend globally, potentially disrupting the global tech supply chains. (Goodman et al., 2019)

South Korea viewed Japan's export restrictions as a punitive measure in retaliation for the Supreme Court ruling, thus politicizing what was previously a purely economic transaction. Conversely, Japan refuted these allegations, claiming the restrictions were predicated on national security concerns and were in accordance with its obligations under the Multilateral Export Control Regime (MECR) to prevent the proliferation of materials that could be repurposed for weaponry. Japan's suggestion that South Korea might be allowing these sensitive materials to reach North Korea added a layer of international security concerns to the dispute, although South Korea adamantly denied any such breaches.

The downgrading of trade status in August 2019 by Japan, reciprocated by South Korea, marked a significant escalation in the trade dispute. It not only affected the governmental and business relationships but also had a profound societal impact as South Korean consumers launched widespread boycotts of Japanese goods, affecting Japanese businesses operating in Korea.

Efforts to mediate the conflict through the World Trade Organization, as well as direct diplomatic engagements, have thus far been unsuccessful in bridging the divide. The strain in relations threatened to undermine collaborative security efforts, as seen in South Korea's consideration of withdrawing from General Security of Military Information (GSOMIA), which had facilitated the sharing of critical intelligence about North Korea's military threats. This step indicated the broader implications of the dispute, stretching beyond trade and economics into the realm of security and alliance politics in a region marked by volatile dynamics and security challenges. (Wang, 2019)

A 2022 paper by Shin and Balistreri (Shin and Balistreri, 2022) simulated the impact of this dispute by using a multi-region general equilibrium model[1] using data from the accounts and observed trade responses in the Korea Customs Service data. They found that a welfare loss of 0.144% ($1.0 billion) for Korea and 0.013% ($346 million) for Japan. Additionally, impacts on sectors include a 0.25% reduction in chemical production in Japan. While in Korea the reduction in imports from Japan is offset by increases in domestic production and imports from other countries. It is noted however that there are many factors not taken into account in their model, such as boycotted products that are produced by Japanese multinational corporations operating outside of Japan, leading to the results understating the actual welfare impacts and trade destructive nature of the dispute.

The resulting changes in import are summarized in figure 2.1 taken from their article.

Source: Author's calculation from Korea Customs Service (January to December 2019).

Affected products	Origin of imports	"Before" (Metric ton: 1000 kg)	"After" (Metric ton: 1000 kg)	Value difference (Metric ton: 1000 kg)	Percent difference (%)
Boycotts					
Automobiles	Japan	8,699.16	5,764.60	−2,934.56	−33.73
	All	42,471.74	50,625.26	8,153.52	19.20
Beer & Cigarettes	Japan	6,670.39	133.72	−6,536.67	−98.00
	All	32,428.21	27,412.06	−5,016.15	−15.47
Cosmetics	Japan	811.91	615.06	−196.85	−24.25
	All	8,328.39	8,193.20	−135.19	−1.62
Processed Foods	Japan	2,353.41	1,569.40	−784.01	−33.31
	All	55,629.51	53,047.90	−2,581.61	−4.64
Export controls					
Fluorinated Polyimide	Japan	787.53	773.84	−13.69	−1.74
	All	1,193.14	1,161.26	−31.38	−2.67
Hydrogen Fluoride	Japan	3,096.47	442.60	−2,653.87	−85.71
	All	10,140.63	8,364.54	−1,776.09	−17.51
Photoresist	Japan	222.17	208.24	−13.93	−6.27
	All	703.31	546.56	−156.75	−22.29

Note: "Before"—monthly average of January to July. "After"—monthly average of August to December. We process the data from the following HS code: automobiles (4-digit level 8703), beer (6-digit level 220300), cigarettes (4-digit level 2402), cosmetics (4-digit level 3303, 3304, 3305, 3306, and 3307), processed foods (2-digit level 18, 19, and 21), fluorinated polyimide (6-digit level 392099), hydrogen fluoride (6-digit level 281111), and photoresist (6-digit level 370790).

Figure 2.1: Changes in import weight over the trade dispute (Shin and Balistreri, 2022)

[1] General-equilibrium simulation models are a class of economic models that use real economic data to estimate how an economy might react to changes in policy, technology or other external factors

Figure 2.2 reports the welfare impacts on percent change and million-dollar value as a result of the trade dispute. This table is adapted from table 5 in the same article, extracting only the result of the Japan–South Korea trade dispute. (Shin and Balistreri, 2022) We can see a net loss for many states in Asia, and an increase in states in the West, such as the EU and China, whom fill in for the lost import and exports from Japan and South Korea. It should be noted however that their model is a relatively short-run assessment of the impact. Shortages in supply chains, the dynamics of foreign direct investment, and outsourcing are not included. This would undoubtedly lead to further losses for all states dependent on semiconductor production.

Regions	% change	Million USD
Vietnam	0.010	15.14
Malaysia	0.000	−0.06
Mexico	0.003	25.11
Taiwan	−0.005	−9.96
Thailand	0.002	3.84
Canada	0.001	7.61
Brazil	0.000	0.24
Japan	−0.013	−345.69
Rest of Asia	−0.001	−14.23
Korea	−0.144	−1,033.71
European Union	0.002	217.91
Australia	0.001	8.55
Rest of the World	0.001	56.64
Mideast Asia	0.011	89.98
Russia	0.003	32.11
United States	0.000	11.88
China	0.003	116.29
World	−0.002	−818.35

Figure 2.2: Welfare impacts due to the trade dispute (Shin and Balistreri, 2022)

2.2 Prior Research

Research on Japan–South Korea relations have largely focused on the unresolved issues from Japan's colonization of the Korean peninsula. (Deacon, 2022) Major points of contention include ownership of the Liancourt islands, forced wartime labor, sexual slavery, as well disagreements on historical accounts. These issues together with the resulting animosity are pointed out as major roadblocks in increased diplomatic cooperation. (Cooney and Scarbrough, 2008; Glosserman and Snyder, 2015; Kagotani et al., 2013)

There has been less scholarly research conducted on the current trade dispute due to its recency, but those that exist have also mostly focused on historical issues and animosity, as the explanatory factors for the unresolvable nature of the dispute. (Wang, 2019) gives a review of the dispute entertaining possible factors ranging from the United States distancing itself from negotiations, historical animosity hindering progress, as well as competition in innovation. (Lim and Tanaka, 2022) hypothesized a psychological aspect contributing to the dispute continuing despite causing significant economic harm. Their key findings suggest that the public in both states becomes more defiant and less supportive of de-escalating an ongoing dispute when informed about the high costs of trade restrictions on domestic firms. These findings support the psychological explanation that the perception of economic loss incites anger and risk-taking attitudes, which counteracts the rational economic incentive to de-escalate conflicts. Deacon's (2022) (Deacon, 2022) paper presents the 2019 trade dispute as a case study to illustrate how historical memories and issues are invoked in the contemporary context, affecting the bilateral relations between Japan and South Korea. He argues that national identities and foreign policies continually influences and shapes the other. This interplay leads to the persistence of the 'history problem', as historical grievances continue to influence present-day policies and attitudes. The same conclusion was reached by Nugroho and Bahri (2019) (Nugroho and Bahri, 2019), citing South Korea's collective memory of past injustices. Tamaki (Tamaki, 2020) argues that the dispute is the product of a self-fulfilling prophecy. The narratives about the other states have solidified over time, making it challenging for either side to make concessions without seeming weak or losing face domestically. And these sentiments have in turn led to policies that perpetuate these views, further perpetuating the difficulties.

Finally, the research most closely aligned to this thesis, comes from a 2019 paper by Sakaki (2019), who refocuses the dispute in light of strategic considerations. Sakaki notes that divergent approaches to regional security, particularly in dealing with North Korea and China, further complicate their relationship. South Korea's efforts to improve ties with Pyongyang and Beijing are viewed with skepticism by Japan. Sakaki concedes that "*the true reason for the tightening of export controls, however, is likely to be the Japanese government's ire over South Korea's actions in the dispute over compensation for former Korean forced laborers. Tokyo wants to persuade Seoul to make concessions.*" (2019)

2.3 Contributions to the literature

While the body of literature surrounding Japan–South relations are extensive, there remains a notable gap in the application of formal analytical frameworks, such as Game Theory, to understand the strategic interactions between the two nations. The bulk of research on the 2019 dispute overwhelmingly consider historical reasons as the major contributing factor hindering progress. This thesis, instead aims to follow Sakaki's approach and analyze the strategic motivations involved in the dispute. Rather than staging the dispute as a result of a decades long impasse, the thesis, instead, frames the dispute as a result of the interaction of the state's strategic interests. By employing game-theoretical models to dissect the complex dynamics at play, presenting a structured analysis the thesis aims to offer a purely rational explanation. The benefits of this type of explanation is that it frames the dispute as a case in a more general framework of international disputes.

Furthermore, by examining the trade conflict through the lens of Game Theory, this thesis aligns with the emerging research that seeks to understand the underlying economic and security-based motivations of state actions (Breslin and Nesadurai, 2023). Game Theory's capacity to model the anticipated payoffs and strategies can clarify why negotiations have stalled and what potential resolutions might be viable given the actors' preferences and constraints, which might offer a different (if not more optimistic) view on how negotiations can resume.

Chapter 3

Method and Theory

This chapter is divided into three main sections. The first section introduces the main theory and assumptions made in Game Theory and introduces key concepts on a theoretical level. The next section details how this theory is specifically implemented in code and the algorithms used. This section is noticeably less approachable as it uses mathematical notation and formal algorithms, but is necessary to formally document the methodology and establish mathematical rigor. The final section discusses the research design of the thesis, commenting on the implications of the method and how this affects the validity and reliability of the research. I also address my motivations and reasoning for this research design.

3.1 Theory

The dispute can be seen as states using coercive statecraft in order to further their interests. It therefore lends itself well to being analyzed with a realist perspective. Realism implies that the central actors are states. The international political system is assumed to be an anarchy, meaning that there is no supranational authority above the states to enforce rules. Further, rationality is assumed meaning that states will act in their rational self-interest. The rationality assumption will be detailed further below. This thesis will use two game theoretical models to illustrate Japan and South Korea's strategies. I will therefore give a brief overview of Game Theory, the assumptions it entails, and how I plan to apply Game Theory in this thesis.

3.1.1 The Rationality Assumption

Game Theory fundamentally relies on the assumption that players involved in the strategic interaction are rational. Elster (1986) posits the criteria necessary for an actor to be considered rational: Players' preferences must be complete and transitive. Completeness implies that an actor is capable of comparing and ordering all possible outcomes, indicating a preference for one over another or being indifferent between them. Transitivity ensures that if an actor prefers outcome X over Y, and Y over Z, then the actor must logically prefer X over Z as well. Moreover, rational players are expected to engage in utility-maximizing behavior, consistently choosing the course of action that aligns with the best possible outcome according to their preferences and beliefs.

The unitary actor model is an extension of this assumption. In our case the players are states, which are then treated as monolithic entities capable of making decisions that maximize their utility in a manner akin to a rational individual. This simplification enables analysts to model the complex interactions of international relations within a game-theoretic framework.

This assumption, however, is not free from criticism. The unitary actor model has been particularly scrutinized for its propensity to overlook internal complexities such as political dynamics, the impact of non-state actors, and bureaucratic procedures that may influence state behavior (Clarke, 1989). Real-world decisions are often the product of intricate political processes involving multiple stakeholders with diverse interests, which the model may fail to capture adequately.

Despite these critiques, proponents like Hovi & Rasch (2006) argue that the rational choice theory can still hold validity in analyzing state actions by considering that, despite internal complexities, the final decisions regarding a state's foreign policy tend to be made or approved by a central authority or position. This assertion holds especially true in matters of international significance or those involving national security, where executive decisions are often streamlined.

Recent scholarly work has moved towards more nuanced models that attempt to account for the internal decision-making processes within states. (Midlarsky et al., 1994) These models examine how individual, group, and institutional interests within a state may affect its external behavior, adding depth to the analysis and addressing some of the criticisms leveled against the rationality assumption.

This will be explored in chapter 6 which uses a two-level game to capture this interaction.

Moreover, behavioral Game Theory has emerged to address the deviations from rationality observed in actual human behavior. This field incorporates findings from psychology and empirical studies to better understand how real-life decision-making may differ from the idealized rational model, such as in cases of bounded rationality, where actors make decisions with limited information and cognitive resources.

In the context of the Japan–South Korea trade dispute, applying the rationality assumption requires careful consideration of each country's historical grievances, domestic political climate, economic objectives, and geopolitical strategies. While the rational actor model provides a foundational framework for analysis, acknowledging the complexities and potential departures from pure rationality is crucial for a comprehensive understanding of the dispute. It would be beneficial to complement game-theoretic analysis with insights from political science and behavioral economics to capture the full spectrum of factors that influence state behavior.

3.1.2 Game Theory

Game Theory is a theory of interactions between rational actors. Interaction occurs when actions made by two or more actors lead to an outcome. Jon Hovi identifies five components of Game Theory: 1. Players: the actors who will make decisions in the game, as well as a non-player referred to as "nature" which is used to simulate chance moves in the game. 2. Strategies: a plan that describes all the actions a player can make. 3. Outcomes: the possible end-states of the game, usually described with what actions took place to reach a certain end-state. 4. Payoffs: the utility all players receive at a given outcome. It is often expressed in cardinal or ordinal numbers. 5. Rules: other rules of the game such as specifying the sequence of moves, and what information is available to a player when they make a move. (Hovi, 1998, p. 4)

The first model will represent the dispute as a series of static games represented as a payoff matrix. These are the simplest models, and as such makes several assumptions. First of all we assume complete information, both players are aware of their own and the other player's payoff. Secondly both players play their actions simultaneously. The solution strategy for this game will be the Nash Equilibrium (NE). NE is the set of actions where each player knows the other's equilibrium strategy, and choose the action where they have no incentive to change their own strategy. In other words the players all choose the action that is the best response to the other's strategy.

The next chapter sees the dispute modeled as a sequential game, where the players take turns with their choices. This game will be represented in extensive form, meaning that the player's choices are represented visually as nodes branching off in a decision tree. The solution to this game is in the form of a Subgame Perfect Equilibrium (SPE). This is a refinement of the Nash equilibrium, which contains the equilibrium strategy of both players for every sub-game, even if those decision nodes won't be reached in practice. This is done using a process called backwards induction, in which the last decision node is considered first, finding the optimal move in that node, and then working backwards until the best action is found for every possible situation. The player's strategies and utilities are common knowledge. (Gibbons, 1997)

The next model that will be analyzed is a dynamic game with imperfect information (sequential Bayesian game). Imperfect information implies that at least one player is uncertain of the type of the other player(s). This will be represented with a dashed line in the model. Further, this will be a screening game, meaning that the uninformed player will start first, and the informed player will choose their action in response. The uninformed player will then update their beliefs on the other players type based on their actions. The player's type is based on a variable the uninformed player is uncertain about. A game with imperfect information is often depicted with an added player called "Nature" which chooses its action based on a probability P. It is this action that leads to the information set where the next player is uncertain of which action node they are currently on.

We will use Perfect Bayesian Equilibrium (PBE) as the solution strategy for this game. PBE is a set of strategies that are sequentially rational given the players' beliefs. The player must also update their beliefs using Bayes' rule whenever possible. The equilibrium can either be a separating equilibrium (where player 1 chooses different actions depending on type), or a pooling equilibrium (where player 1 chooses the identical action, regardless of type). (Gibbons, 1997)

Although several states and interest groups have an effect on the negotiations on this conflict, we will use simplified models represented as two-player games between Japan and South Korea. The remaining components of the game (strategies, outcomes, and payoffs) will be specified when the models are presented.

It is difficult to quantify the utility of state's preferences. The preferences of the states will therefore generally be represented as variables representing the utility of a given outcome. These variables principally represent various aspects of the state's utility, such as economic and political gain and repercussions. These variables are used in the analysis to reason on why the states subscribe to certain strategies. The ordinal value of the variables themselves are based on empirical research detailed in section 3.3.2.

3.1.3 Two-Level Games

In chapter 6, we will relax the unitary assumption and model the dispute using Putnam's (1988) Two-Level Games. Two level games models international negotiation as simultaneous negotiations occurring on two levels. The first level is the international level where negotiations are between states. The second is the domestic level which includes the national legislature, business interests, and other interest groups of which the chief negotiator in level 1 needs the support of, such as the treaty ultimately needing to be ratified in the national assembly.

The domestic level affects the international level by providing the chief negotiator with a set of win sets which are likely to be accepted by domestic interest groups. The international level then uses these win sets as parameters in their negotiations. (Putnam, 1988)

Normally states are assumed as unitary actors in international politics. By employing two-level games, we are able to combine the units of analysis to include both states and domestic affairs, allowing us to relax the assumption of single unitary actors.

Integrating the two levels in analysis has increasingly been seen as a more complete method of international relations breaking from traditional realist thought. Evans (Midlarsky et al., 1994, p. 397) notes that "*an integrative perspective has come increasingly to dominate contemporary theorizing on diplomacy and domestic politics. (...) the question is no longer whether to combine domestic and international explanations in order to understand conflicts and accords among nations, but how to combine them.*" Putnam's two-level game is one such method that effortlessly integrates into the framework of this thesis.

3.2 Implementation

This section documents how the above theory was implemented into StratPy.[1] I will formalize the theory mathematically and explain the algorithms used. The algorithms are written language-agnostic. The specific Rust implementation of the algorithm is found in the GitHub repository.

3.2.1 Algorithms

Algorithmic Game Theory poses a concerning question, if it is computationally difficult to compute Nash Equilibria, can it then still be reasonably to expect players to naturally reach these equilibria? And if not, can these equilibria really be said to model players' behaviors? These questions have lead to optimizations in equilibria algorithms, some of which are implemented in StratPy.

This section provides formal definitions for these solution strategies and details the algorithms used to provide them. We start with the simplest approach, finding pure Nash Equilibria using best response.

Best response

Let $a_{-i} = \langle a_1, ..., a_{i-1}, a_{i+1}, ..., a_n \rangle$ That is to say a_{-i} is the action sequence of all other players beside player i. The entire action set is thus made up of the actions of player i and a_{-i} $(a = (a_{-i}, a_i))$

The best response for player i (a_i^*) is then

$$a_i^* \in BR(a_{-i}) \iff \forall a_i, u_i(a_i^*, a_{-i}) \geq u_i(a_i, a_{-i}), \tag{3.1}$$

where a_i^* is part of the set of *Best response*, assuming all other players play a_{-i}, if and only if for all a_i, the utility for playing a_i^* when the other players play a_{-i} is greater than or equal to the utility of playing another move, when the other players play a_{-i}.

The Nash Equilibrium is the set of actions where all players play the best response against the other players

$$a = \langle a_1, ..., a_n \rangle \in NE \iff \forall i, a_i \in BR(a_{-1}). \tag{3.2}$$

[1] Further documentation on StratPy usage, installation and algorithms can be found here: https://stratpy.ofstad.co/.

The Lemke-Howson Algorithm

Another algorithm considered when analyzing possible mixed strategies, is the Lemke-Howson algorithm. (Lemke and Howson, 1964) The algorithm assumes a bimatrix game, which is a simultaneous two-player game in which each player has a finite number of possible actions. The payoff matrices are divided by player as A and B. Each strategy and each payoff inequality (derived from the strategy matrices) is assigned a unique label k.

Algorithm 1 The Lemke-Howson Algorithm

Input: A Non-degenerate bimatrix game (A, B)
Output: One Nash equilibrium of the game

```
Choose k ∈ M ∪ N
while l ≠ k do
    Let (x, y) be the current vertex.
    Let l be the label that is picked up by dropping label k
    drop l in the other polytope
end while
The current (x, y) is a Nash Equilibrium of the game
```

The algorithm iteratively navigates through a series of vertices (strategy profiles) in the strategy space, eventually leading to a Nash equilibrium. We start by : Begin by choosing a label k from the set of labels $M \cup N$ where M and N represent the sets of strategies available to each player. The algorithm enters a loop that continues as long as the label l is not equal to the starting label k. At each iteration, (x, y) represents the current vertex in the strategy space, which corresponds to a mixed-strategy profile for the players. The algorithm involves 'dropping' a label l in one polytope (a geometric representation of strategies and payoffs) and 'picking up' a new label by dropping label k in the other polytope. This process essentially swaps one label for another, traversing the vertices of the strategy space. When the loop ends the current (x, y) pair is guaranteed to be a NE of the game. (Nisan et al., 2007)

Sequential Games

Sequential games in extensive form are stored in a tree data structure. Trees are a fundamental data structure in computer science and is a type of linked list which may have multiple relations among its nodes. In our case nodes may have one parent node, and several children nodes. The tree starts with a root node, containing the first decision in the game, be it Player 1 or nature. The leaf-nodes all contain a utility for each player, either as a floating point value or as a custom variable class. These nodes represent the end states of the game. The nodes can also contain an information set, which is shared among the nodes contained with that set.

For games with complete information, we use the backward induction algorithm to find the equilibrium. The algorithm is as follows:

Algorithm 2 Backward Induction

Input: node h
Output: $u(h)$
if $h \in Z$ **then return** $u(h)$
end if
Initialization $best\_util \leftarrow -\infty$
for all $a \in \chi(h)$ **do**
  Initialization $child\_util \leftarrow$ Backward Induction $(\sigma(h, a))$
  if $child\_util_{p(h)} > best\_util_{p(h)}$ **then** $best\_util_{p(h)} \leftarrow child\_util_{p(h)}$
  end if
end for
return $best\_util$

(adapted from Leyton-Brown and Shoham (2022))

Backward induction is a recursive function that takes a node h as an input. To find the sub-game perfect equilibrium the initial node will be the root node of the game. The function outputs the utility of node h. Since the function is recursive the initial step is to check our base case. The base case is if the current node h is part of the set of leaf nodes Z return the utility of that node. Since all leaf nodes are associated with a payoff, the payoff of the node is simply returned. Next we initialize a vector *best_util* of the utility associated with the players. This vector gets updated throughout the current iteration of the algorithm. The initial value of *best_util* is less than any other possible payoff so we set it to negative infinity.

For all actions a in the actions available at the current node $\chi(h)$, do the following (Note that every node has a player associated with it formalized as $p(h)$): We define a new variable *child_util* and initialize it as the recursive result of performing the backward induction algorithm again on the node reached by taking the action a at node h, formalized as $(\sigma(h, a))$. If that utility for the player associated with the node is greater than the current *best_util* for that player, assign *best_util* as that value. After checking all the nodes in $\chi(h)$, return *best_util*.

While this algorithm is defined slightly different than the original description of backward induction, where we start at the end-node and work our way up the tree, the result is the same. The parent node's utility is based on the children's nodes utility which are again based on their children, until end-nodes are reached. The waiting recursive calls then collapse upwards like in the original definition.

3.2.2 Testing

In addition to developing the core functionality of the StratPy package, just as much time and effort was taken in writing and conducting tests for the program. StratPy partially uses test-driven development as presented in Beck's (2002) *Test Driven Development. By Example.* The general idea is that the software's requirements are converted to tests before the relevant functions are written. This is opposed to the more traditional method of writing code, and testing the functionality after the fact. Benefits of using this development framework include being aware of the code's requirements before attempting to solve them, and encouraging writing more tests, usually smaller in scope, which ensure correctness throughout the whole library. The testing of the library can be divided into three main parts: unit tests, integration tests, and deployment tests.

Unit Testing

A unit test is essentially a procedure, or group of procedures, that instantiates a section of the software and verifies its resulting behavior independently from other sections of the software. In StratPy, this is done per file, using Rust's built-in testing functionality. The test functions can be run individually, or sequentially for the whole program, and Rust's compiler outputs the test results indicating which tests passed and failed. An example test can be ensuring that the function for adding nodes, correctly adds the node containing the players name and action to the correct parent node.

Integration testing

While unit-testing tests the individual structures and methods, integration-tests assert that all parts of the program work correctly when used together. Since the library is primarily intended to be used in a python environment, the integration-testing is performed using python. In addition to verifying that the program is integrated correctly, the tests also ensure that the values returned are consistent with our expectations. The testing environment sets up different Game Theory models and compares the result to already documented solutions to the games. For example, the Nash Equilibrium of the prisoners' dilemma game is to play *betray* for both players. The test sets up a prisoner's dilemma and checks that this is indeed the result the program produces. Having these tests not only ensures that the program is working correctly, but by performing these tests after any changes to the code, also ensures that the update doesn't alter the expected result.

Deployment testing

The final testing is to ensure that the library performs correctly on different environments, both in terms of Operating System and different versions of Python. This is one part of a practice known as *Continuous Integration*. The test itself is auto generated by Maturin "Maturin," 2018, the build system of the library, and is performed using GitHub's workflow, after every new commit of the code. The test attempts to build the project on different CPU architectures (x86, x86_64, arm etc.) as well as popular Operating systems, including MacOS, Windows, and the Ubuntu distribution for Linux. Users of different systems should thereby be guaranteed to have access to the same build of the library, and be able to reproduce the same results, increasing the reliability of the research.

3.3 Research Design

The thesis adapts the framework detailed by Morrow in his 1996 book *Game Theory for Political Scientists* (Morrow, 1994). Morrow details how to transition from the situation studied to a formal model. He identifies the single most important step as simplification. Start with simple models with few actions. Through several revisions, add and delete features, with deletions being more common than additions. Secondly vary the existing model. Models don't just provide answers, they also raise new questions. This thesis follows that approach by keeping models simple, and adding complexity and varying assumptions with each new iteration of the models.

As with all models, the games analyzed in this thesis portray an extreme simplification of the dispute. The games are limited to two players, and the interaction is modeled with only one choice per player albeit with the possibility of future repeated interactions. The benefit of this is that the models are easy to use in analysis. Making the model too complex can defeat the purpose of using a model in the first place. The goal is finding a balance where the model is simple without losing its explanatory power.

3.3.1 Limitations and scope

While this thesis limits itself to only considering Japan and South Korea as the players, there are certainly many more actors at play. The United states has a vested interest in quickly solving the dispute as it puts U.S. strategic goals at risk. The military alliance with both Japan and South Korea are the foundation of US foreign policy in Asia. (Klingner and Walters, 2019) The US has however often taken more of a "backseat approach" when dealing with Japan–South Korea relations, heavily encouraging reconciliation without exerting pressure (at least publicly). Since the strategic alliances with the US is in general considered a counter-force to China as the regional power (and to a lesser degree North Korea) (Goo and Lee, 2014), China also has a political interest in the weakening of ties between Japan and South Korea. While these actors are a present dynamic in the dispute, I have chosen to limit the scope to modeling the dispute as a two-player game. As previously stated the US's seemingly hands-off approach, and the difficulty in ascertaining China's effect, is a small justification for this approach. The more important reason is that the simplification allows for less complex models that are both easier to understand and analyze.

3.3.2 Empirical data

The preferences of the states is based mainly on press releases published by the respective Foreign Ministries and the Ministries of Economy, Trade and Industry.[2] Using sources from government agencies, especially about foreign policy, is not without caveats, however, and like all sources should be evaluated.

While press releases from government agencies are the most readily available source for the states policies, they do not necessarily align with a state's real strategy. The sources instead describe their policy as how they wish for it to be presented publicly. This is still valuable information, as long as the purpose of the

[2] The sources provided in the bibliography link to the English translation of the source for the readers convenience. The source in the original language can be accessed through a link on the same page. If not otherwise stated, it can be assumed that the thesis used the original press release.

source is kept in mind. In order to acquire a better understanding of the state's true intentions we can also examine the actions and results of negotiations found in secondary sources as a form of data source triangulation. (Denzin, 1978)

Another potential weakness is that the original press releases are published in the states national language. The provided translations are often abridged versions of the original release where details are left out. The word choice may also have been altered. In fact, the Korean Ministry of Foreign Affairs have the following disclaimer on all their pages "The Korean version is the official version of all news content." (*The Ministry of Foreign Affairs, Republic of Korea*, 2023)

Therefore, since I do read both Japanese and Korean, I've used both the original and translated documents, comparing them to ensure the translation's accuracy. Additionally, to ensure that I captured the nuances correctly, I have enlisted the help of native speakers to verify my understanding of these texts.

The vast literature on Japan–Korean relations and prior research on this dispute specifically (discussed in section 2.2) was also carefully considered to make sure the models were grounded in reality, and to corroborate the results of the models.

3.3.3 Biases

While I have taken courses on both Japanese and South Korean policy-making in their respective countries. I acknowledge a certain imbalance of knowledge in favor of Japan. Having interned at the Norwegian Embassy in Tokyo, I was able to acquire a unique perspective into Japanese foreign policy making by being allowed to participate in meetings with the Japanese Foreign Ministry. While these proceedings are confidential and will therefore not be used in any form as empirical data, the experiences, can potentially create a lopsided level of understanding of the two states. One way to mitigate this was to be cautiously aware of the potential biases this may bring to the research, and also attempting to compensate the knowledge gap with further reading on South Korean policy making.

3.3.4 Validity

In order to ensure measurement validity, this thesis uses the framework introduced in Adcock and Collier's 2001 paper "Measurement Validity: A Shared Standard for Qualitative and Quantitative Research" (Adcock and Collier, 2001), which presents a common framework for measuring validity. I will use their definitions of the different types of validity.

Construct Validity: Game Theory offers a high level of construct validity in scenarios where interactions are strategic and interdependent. The constructs of Game Theory, such as payoffs, strategies, and equilibria, are well-defined and correspond closely to the concepts they intend to model in strategic decision-making processes.

Content Validity: The method is valid if the game accurately represents the range of options available to the actors involved in the dispute. For the Japan–South Korea trade dispute, the models are valid if they can encapsulate the political strategies and counter-strategies that the countries can employ. This concept must also be balanced with the simplicity of the model, however. Since our goal is to create a model with as much explanatory power with the least complexity, strategy sets are often merged or simplified into a single action.

External Validity: This is concerned with the generalizability of the findings. Game Theory's conclusions are often valid under specific conditions or assumptions, such as rational behavior and common knowledge. While these assumptions may not always hold in real-world situations, game-theoretic models can still provide valid insights into the potential outcomes of strategic interactions. The rational aspect of the theory also helps generalize the findings, as players in similar situations with similar preferences are more likely to choose the same strategies.

3.3.5 Reliability

Internal Reliability: Game Theory is a mathematically rigorous method, which ensures that the conclusions derived from a well-constructed model are internally consistent and reliable. If the initial conditions or strategies change, the model can reliably predict how these changes affect the outcome. Furthermore the use of the StratPy package helps ensure internal reliability by reducing calculation errors. The extensive testing modules also assert the models correctness. Finally due to the export function, the models used for analysis are guaranteed to be the same figures seen in the thesis.

Inter-rater Reliability measures the likelihood of different analysts reaching the same conclusions. The formal structure of Game Theory should allow for this type of reliability to remain reasonably high as long as the analysts are given the same information about the players' preferences, strategies, and the structure of the game. Other analysts can disagree on the configurations chosen in the thesis, however, leading to different predictions.

Test-retest Reliability measures the consistency of research when performed several times. Game-theoretic models can yield reliable results over multiple tests as long as the underlying conditions remain the same. However, in dynamic real-world situations where actors' preferences and strategies may evolve, the specific outcomes predicted by a game-theoretic model may not be consistently replicable. On a theoretical level however, game theoretical models should also score highly for this measure.

Furthermore, the code of all the models is provided in the appendix, and the source code for the library itself is also made publicly available. This should ensure that researchers who want to replicate the results have access to the same tools and methods used in this thesis, thus improving transparency and reliability.

3.3.6 Summary

In the context of the Japan–South Korea trade dispute, Game Theory can be considered a valid method for exploring possible strategic moves and outcomes. It can help in understanding how each country might weigh different decisions' costs and benefits, considering the historical and socio-political context that influences these decisions.

However, the assumptions of rationality and perfect information are particularly important to scrutinize. In reality, nations may act under bounded rationality—where decisions are rational but limited by the information and cognitive limitations of the decision-makers. Additionally, political decisions are often influenced by domestic political pressures, historical grievances, and cultural factors that may not be easily quantifiable or predictable by game-theoretic models.

To enhance the validity and reliability of using Game Theory in this context, it was therefore crucial to make sure: I use a range of models to capture different aspects of the dispute, and to research empirical data to inform the payoffs and strategies used in the models.

While Game Theory provides a powerful and reliable analytical framework, its application must be carefully tailored to the complexities of international relations, acknowledging the nuances that affect state behavior beyond what is typically captured in theoretical models.

Chapter 4

Static Games

This chapter models the dispute as simultaneous games. I will consider different approaches to how this can be done, and what insights can be gained. This chapter will also set the stage for the following chapters which will attempt to solve different aspects of the shortcomings of this simplified approach.

4.1 Game of Chicken

The first model to consider is a static game represented by a payoff matrix where the players act simultaneously. Player 1 (Japan) is represented as the actions in the columns, while Player 2 (South Korea) is represented by the rows. The first payoff in the cells belong to Japan, and the second to South Korea. For example, if Japan plays $Negotiate$ and South Korea plays $Escalate$ the $<-5, 1>$ outcome is reached, giving Japan a payoff of -5 and South Korea a payoff of 1. While the specific choice of number is largely arbitrary, they represent the severity of the outcome, and thus the degree to which certain outcomes are preferable to the players.

The model represents the following situation: The Supreme Court of South Korea decided in favor of Japanese companies being liable for compensation to wartime forced laborers. In return, Japan suspended the export of materials used in semiconductor production. The two players are now faced with two possible strategies. They can either $Negotiate$, representing the state's willingness to compromise in order to reach an end to the dispute, or $Escalate$, in which case they continue their punitive actions against the opponent.

		South Korea	
		Negotiate	*Escalate*
Japan	*Negotiate*	-1, -1	-5, 1
	Escalate	1, -5	-10, -10

Game of Chicken

Figure 4.1: Naive Model

If both states decide to *negotiate*, the dispute will come to an end. However, since this entails a compromise, a small cost is incurred. If both states decide to *escalate*, however, the worst outcome is reached where the economic losses of the trade war continue to grow. If one of the players decides to *Escalate* while the other *Negotiates* the player trying to negotiate suffers the costs inflicted by the other player without inflicting any damages themselves.[1] The player who plays *Escalate*, however, is allowed to protest through economic statecraft without suffering the damages of reciprocated punishment.

This situation is known as a dilemma of common aversions. Its defining characteristic is avoiding a mutually damaging outcome. (Zartman and Touval, 2010) The model of this situation is often referred to as the game of chicken, a game extensively studied both theoretically and for its applications in international relations. (Smith and Parker, 1976; Snyder, 1971; Zartman and Touval, 2010)

Another interesting characteristic of the game are its equilibrium states. The two Nash Equilibria are the two outcomes where one player *Negotiates* and the other *Escalates*.The mutually beneficial outcome where both players decide to negotiate is negated by the fact that each player has an incentive to renege in order to acquire a higher payout. This also runs the risk of ending in the worst outcome for both players. As such, the players will want to compel the other player to chose *negotiate*. This can be achieved by either convincing the other

[1]Since the model only has two actions per player, the actions can be thought of as capturing more than just negotiating, but also the willingness to compromise, and more importantly the absence of escalating the dispute.

player that they will play *Escalate* regardless thus leaving the only rational choice for the other player to choose the other option in order to avoid the worst outcome, or by attempting to form an agreement for both parties to choose *Negotiate* but then renege on the agreement to gain their preferred outcome.

This type of game makes it difficult to achieve solutions to the dispute. The two outcomes where one player "wins" and the other player "loses", are the two technical equilibrium points in pure strategy, but the asymmetry in the relative gains that lead to this outcome is also what makes the outcome unstable. This instability makes the game prone to cheating and defections. This results in the mutually beneficial outcome $<Negotiate, Negotiate>$ being difficult to reach without a great deal of trust between the players, a characteristic that is lacking between Japan and South Korea.

While this model does shed light on the difficulties of reaching a negotiation in these types of disputes, the equilibrium strategies are lacking when compared to how the dispute played out in reality, where both players choose to escalate. Furthermore, the model makes the naive assumption that the preferences of the players is mainly determined by the economic gain and loss of a given outcome. While this did still explain the instability of the position, in the next model we will address the weaknesses of this model by introducing an additional variable to the player’s utility: If the player decides to negotiate but the other decides to refrain some cost C is incurred.

4.2 Prisoner’s Dilemma

We consider the same configuration as the previous model with a few changes. Now the outcome where a player chooses to *Negotiate* while the other *Escalates* incurs an additional cost C. We assume this C when subtracted with the base utility of the outcome (-5) to be less than the outcome gained in the outcome $<Escalate, Escalate>$. That is to say: $-5 - C < -10$. This small addition changes the best responses of the players, and results in a Prisoner’s Dilemma game.

		South Korea	
		Negotiate	*Escalate*
Japan	*Negotiate*	-1, -1	-5 $-\ C$, 1
	Escalate	1, -5 $-\ C$	-10, -10

Prisoner's Dilemma

Figure 4.2: Prisoner's Dilemma

The prisoners dilemma is another classic model that has been widely used for representing disputes. (Axelrod and Axelrod, 1984) While similar to the previous model, there is an added risk for playing *Negotiate*. If the other player decided to *Escalate* the first player end in their worst possible outcome. This risk is the defining trait of the prisoners dilemma leading to the dominating strategy of always *Escalating*, which is indeed the Nash Equilibrium and solution to the game.

The cost C can represent a myriad of factors detrimental to the state if they should find themselves in this outcome. C as a form of audience cost will be explored in chapter 5, while in chapter 6 C represents the domestic constraints placed upon the negotiator. To keep consistent with our economic assumption, we will consider another game that can factor into the cost C. Namely the loss of market share in the semiconductor industry.

4.3 Zero-Sum game

As market share represents the percentage of an industry. For an entity to gain market share, another has to lose market share. Models that capture this dynamic are called zero-sum games, where one player's gain is equal to another player's loss, resulting in a net zero utility.

South Korea

		Negotiate	*Escalate*
Japan	*Negotiate*	0, 0	$-M_1$, M_1
	Escalate	M_2, $-M_2$	0, 0

Zero-Sum Game

Figure 4.3: Market Share Competition

The players and action sets are the same as the first two models, although we are now modeling a more specific aspect of the dispute. In this payoff matrix, the utility only accounts for the relative gain and loss of market share as a consequence of the dispute. The situation is as follows: If both players *Negotiate* an end to the dispute, the market share returns (or remains) at the previous status quo. This results in a net zero payoff for both players. Likewise, if both players decide to continue the dispute, the relative market share remains the same.[2] The last two outcomes are reached when the players perform asymmetric strategies. If Japan *Negotiates* and South Korea *Escalates*, we see a situation where Japan is willing to compromise and reverts their decision to ban exports. South Korea, however, decides to and find alternative import sources as well as increasing domestic production, altering the market share in South Korea's favor represented by the variable M_1. On the other hand, if South Korea decides not to escalate, or punish Japan, they lose market share due to the loss of access to Japan's semi-conducting materials, represented by the variable M_2.

This game looks at a specific and relatively small part of the overall utility considerations of the dispute as a whole. Seen in conjunction with the previous Prisoner's dilemma model, the market share model helps justify the cost variable C. Since the original dispute started with the limitations placed on semi-conductors, this was used as the basis for this model, but it can it also be thought of as

[2]In all likelihood, there will be some loss or gain in market share, as Japan continues banning the export of the key materials, and South Korea finds alternative providers. For the sake of simplicity, however, we assume that the relative gains and losses are negligible, at least compared with the two other outcomes.

representing market share gains and losses in other sectors due to the ensuing boycotts. Regardless, the model helps explain the potential loss that can be encountered should one party *Negotiate* and the other *Escalate*, and how a potential prisoner's dilemma situation could arise.

4.4 Results and Implications

Both the Game of Chicken and the Prisoners Dilemma demonstrate the difficulties in reaching agreements. The Game of Chicken demonstrates this by giving both players the incentive to try to reach their preferred outcome, while leaving the other to accept some losses in order to prevent an even worse outcome. While in the Prisoner's Dilemma, the Pareto optimal and mutually beneficial outcome of resolving the dispute is never reached due to the risk of the other party betraying the other to gain an advantage, leaving both parties dominating strategy to be to *Escalate*.

While the situation seems bleak, these models also provide the possible strategies for cooperation. Axelrod describes in his book *The Evolution of Cooperation* (Axelrod and Axelrod, 1984), how cooperation can emerge when actors follow their self-interests. In the Prisoner's Dilemma Game, he advocates for a tit-for-tat approach, in which each player copies the actions of the other in a previous iteration of the game. He found that the players will quickly learn that cooperation is reciprocated with cooperation resulting in mutual benefit, where as conflict is returned with conflict, leading to a sub-optimal outcome for both parties. Thus given an iterated game where the end is not known (an uncontroversial assumption to make in political science), the players will develop trust through repeated interactions and learn to cooperate.

The Game of Chicken is not as clear cut as it lacks the mechanism of reciprocal defection, as doing this leads to the outcome both players are tying to avert. The instability of the game and the lack of mechanisms that can be exploited in repeated games makes The Game of Chicken difficult to solve in non-cooperative games. Evans(Midlarsky et al., 1994) notes that for dilemmas of common aversions, either some degree of mutual trust must be present, or a mechanism must be established to guarantee compliance and/or punish defection. In the field of international relations, if we assume a realist anarchy, it is difficult for this mechanism to come into play, but using a more liberalist viewpoint one might expect institutions such as the World Trade Organization (WTO) to be able to fill this role.

The models do not account for broader economic or political consequences of the dispute. For instance, trade restrictions could lead to global supply chain disruptions, affecting industries and economies worldwide. Rather it looks at the immediate, or short-range consequences. Another weakness with the models are that the players have to commit to their strategies without knowing what the other player will do. In the next chapter I will look at models that takes this into account by looking at the actions sequentially. This makes it possible for the players to react to moves made by the other, and is therefore a closer representation of the interactions between the two states.

Chapter 5

Sequential Games

This chapter expands the previous models by adding a sequential element to the game. The first player chooses an action and the second player can in turn respond with their own action. Games with both perfect and imperfect information will be analyzed.

5.1 Complete Information

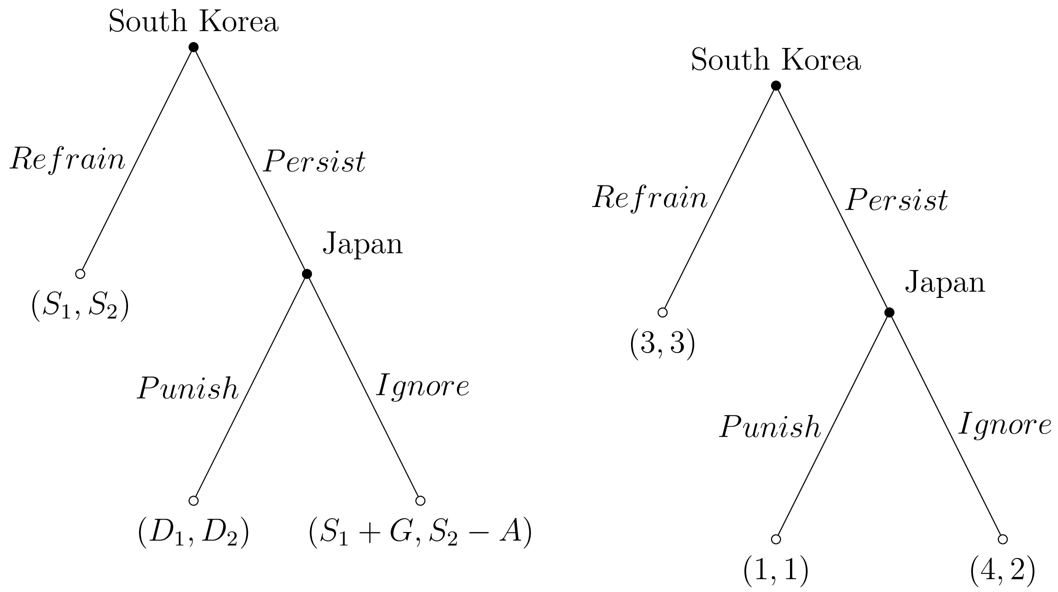
Player 1 is South Korea, who first plays an action, where the second player, Japan, can play a response depending on the previous action. The first choice represents South Korea having a choice of either demanding further compensation for forced workers represented by the action *persist*, or doing nothing thereby maintaining the status quo, represented by the action $refrain$. If *persist* is played, Japan can either choose to *punish*, which in our case means setting limits on exports of key material, or do nothing, represented as *ignore*.

The payoffs are the utility gained by the two players in each possible outcome of the game. Player 1's utility is listed first, followed by Player 2's utility. S_1 and S_2 is the utility of maintaining the status quo. This implies the benefit received from regular free trade between the states. $D1$ and $D2$ is the utility received in the situation where Japan decides to *punish* resulting in the escalating dispute we see today. If Japan plays *ignore*, South Korea receives the same utility as $S1$ in addition to the audience gain received by winning a case against Japan. Japan in turn, receives the utility of $S1$ minus an audience cost A incurred by the Japanese constituents by accepting to pay compensation.

South Korea thus has the preference: $S_1 + G > S_1 > D_1$, and Japan the following preference: $S_2 > S_2 - A > D_2$.

We assume complete information, meaning the utility and strategies are common knowledge to both parties. We also assume it is common knowledge that Japan regards persist as undesirable.

Model 5.1a displays the utilities as given. In order to improve readability and ease of understanding I have included an identical model 5.1b, where the utilities are replaced with ordinal numbers, 4 being the most desirable outcome and 1 being the least desirable.



(a) model 5.1a

(b) model 5.1b

Figure 5.1: Credibility Problem

Here we can already see that there is a credibility problem. Japan cannot credibly threaten to *punish* when *ignoring* gives a higher payoff. *Punish* is therefore a strictly dominated strategy. The threat is thus empty, resulting in South Korea choosing *Persist* which will net South Korea a higher payoff than refraining as $S1 + G > S1$. The Subgame Perfect Equilibrium is thus:
SPE $<Persist, Ignore>$

This outcome explains why South Korea originally chose to go ahead with demanding compensation but does not explain Japan's resulting reaction.

In a single stage game, it is irrational for Japan to punish. However, interactions between states are rarely a one time event. If the same base game is repeated multiple times, the strategies differ as well. By opting to choose punish every game, it is now irrational for South Korea to choose persist, as the payoff $S1$ is larger than the guaranteed payoff of $D1$. Given perfect information the resulting strategy would thus be: $<Refrain, Punish>$, Where the punish node is never reached, since South Korea starts by playing Refrain.

This, however, does still not accurately describe the dispute, as South Korea did in fact $persist$. We will therefore look at a new model that does not assume complete information.

5.2 Imperfect Information

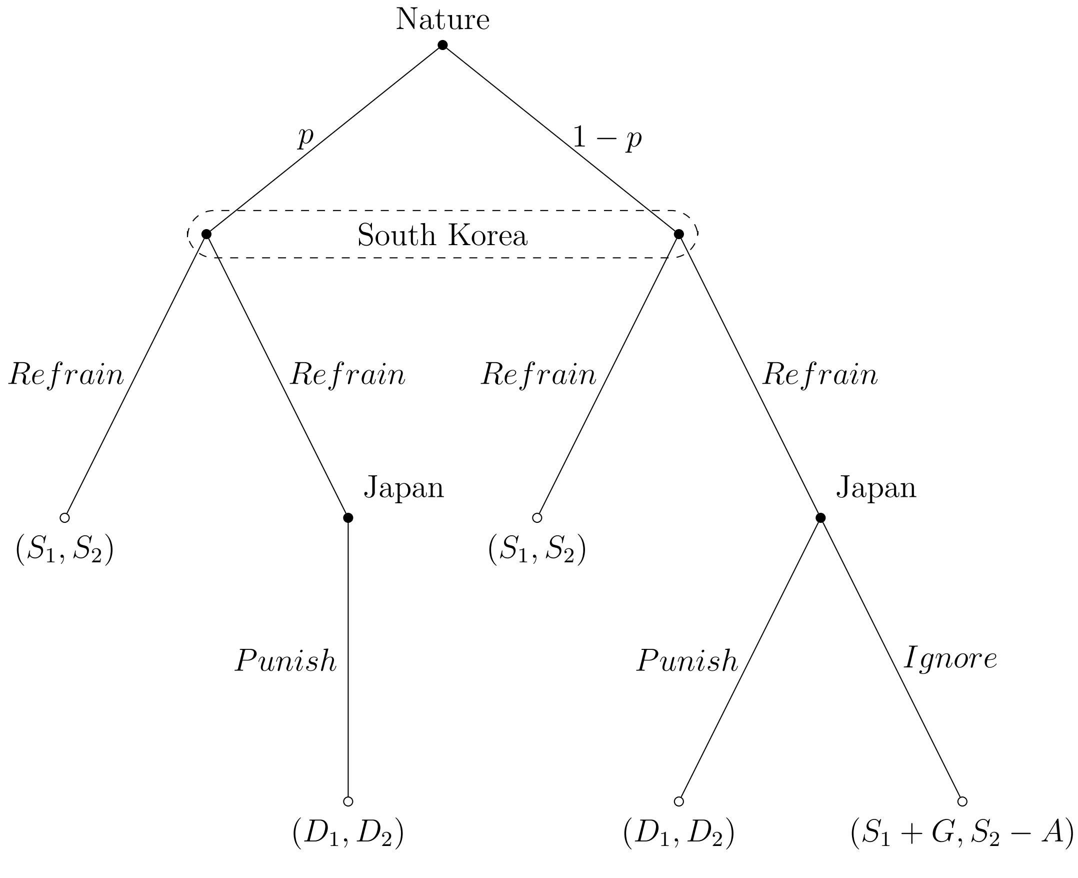


Figure 5.2: Game with imperfect information

This model shares the same actions and utilities as the previous model. In this screening game, Player 1 is uncertain of Player 2's type. Type A represents Japan's willingness to pursue punitive measures in order to affect future action the ignore option is therefore removed, while Type B is identical to the previous game. South Korea believes that Japan is type A with probability p and likewise type B with probability $1 - p$. Japan's strategy is straight forward. As type A Japan has committed themselves to always playing punish. Type B follows the same logic as the previous game and therefore would prefer to ignore. South Korea will therefore prefer to refrain if Japan is Type A and Persist if Japan is type B. In order to find South Korea's opening move we need to calculate the payoffs on each side multiplying with the probability of Japan's type:

$$U(Persist) = p(D1) + (1-p)(S1+G) > S1$$

Simplifying gives us the following:

$$p = \frac{G}{D_1 - S_1 - G}$$

Given that $S1 + G > S1 > D1$, it is likely that p must be more than ½ for South Korea to choose to refrain. Thus, if no other belief indicates otherwise, it is more likely for South Korea to choose persist. The Perfect Bayesian Equilibrium is thus:

- If $p > G/D1 - D1 - G$ South Korea Refrains
- If $p < G/D1 - D1 - G$ South Korea Persists
- Japan punishes if *typeA* and Ignores if *typeB*
- South Korea's belief is that Japan is *typeA* with probability p

After any repetition of this game South Korea can now update their belief about Japan's type using Bayes rule:

$$P(A|B) = \frac{P(B|A)P(A)}{P(B|A)P(A) + P(B|\sim A)P(\sim A)} \tag{5.1}$$

$p(1)/p(1) + (1-P)(0) = p/p = 1$

In this case, the results are self-evident. If South Korea observes Japan punish, South Korea's new belief will be that Japan is type A with probability 1.

By choosing to persist in the first game, Korea can screen Japan's type, and will choose to refrain in the subsequent games. This is the outcome we see in real life, where the sub-optimal outcome $<Persist, Punish>$ is reached. After this initial game, this model predicts all subsequent games will result in $<Refrain, Punish>$, again meaning that the punish action node will never be reached.

5.3 Results and Implications

The implications of these models suggest that Japan uses the interaction to signal its implicit threat for future interactions.

While short term, this incurs a loss to both sides and is a seemingly irrational move for Japan. If we consider repeated interactions, however, South Korea will be more wary about conducting similar court judgments going against Japanese interests. In fact, a more recent court case in Korea dealing with a similar situation, sided with Japan. The court overturned an earlier ruling that decided that the Japanese government must pay compensation to Korean victims of forced-prostitution during the war. This mirrors the original cause of the trade dispute where there was disagreement on weather the 1965 normalization treaty (Treaty on Basic Relations between Japan and the Republic of Korea, 1965) had settled all wartime disputes or not. This time, however, the court sided with Japan. (Sang-Hun, 2021) This could indicate support for the model which predicted subsequent games to result in $Refrain$.

By keeping the threat implicit, Japan is able to signal its intentions for future interactions, without explicitly stating what they are, thereby safeguarding itself from any potential problems with the World Trade Organization. This is further facilitated by securitization of the issue; Japan argues that limiting export is a matter of national security and is thus justified as it is merely following its duty as a member of the Multilateral Export Control Regime. (METI, 2019)

Chapter 6

Two-Level Game

This chapter[1] will consider the constraints domestic policy has on international negotiations by modeling the dispute as a two level game. The first level is the international stage where South Korea and Japan negotiate state to state. The second level models the domestic concerns as a win set, representing the bargaining room that is acceptable on a domestic level.

6.1 Modeling and Analysis

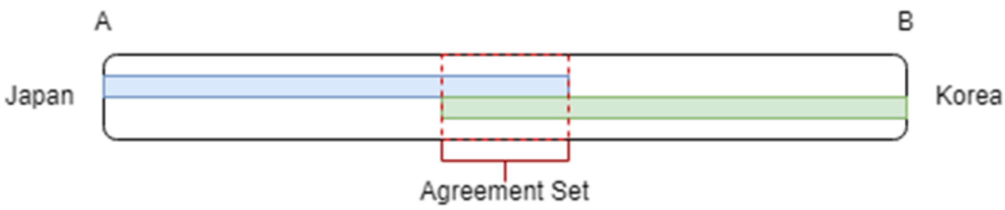


Figure 6.1: The Agreement Set

Figure 6.1 shows the first level of the game as a position plot between the two states preferred outcomes: A being Japan's preferred outcome and B being Korea's preferred outcome. The blue bar indicates the range of positions acceptable for Japan, and likewise the green for Korea. The area where these positions overlap is what Putnam calls the agreement set. (Putnam, 1988) This area is acceptable to both parts, and so the outcome of negotiations will be somewhere inside this set.

This figure is a model of level 1 without the influence of level 2 and shows the negotiators original positions. Although both states have their ideal outcome

[1]This chapter is based on an earlier term paper submitted in STV4228B - Game Theory and International Cooperation, Spring 2022

on either side, they are both willing to make concessions in order to ensure an agreement is made.

In this thesis I will primarily focus on the Japanese side for simplicity. As previous studies suggest, there is a present discontent towards Korea especially among the conservative faction of Japanese society. (Yoon and Asahina, 2021) Since the current leading party (LDP) is dependent on the conservative vote, they have a vested interest in limiting policies that their core voting groups dislike. A more current example of this can be seen during the COVID years. While most states opened up for visitors relatively quickly after the situation stabilized, Japan's borders remained closed for a considerably longer time despite huge losses due to lack of tourism. This policy was hugely popular however, with 89% of Japanese citizens polled being in favor of the ban on foreign arrivals. (The Japan Times, 2021)

Level 2 takes these domestic concerns into account and results in a more limited range of acceptable positions. Figure 2 overlays this new range over Level 1's original range of positions. This new range is called the Win set. In order for an agreement to take place, the two win-sets need to overlap. Since there is no overlap in this model, no agreement can be reached.

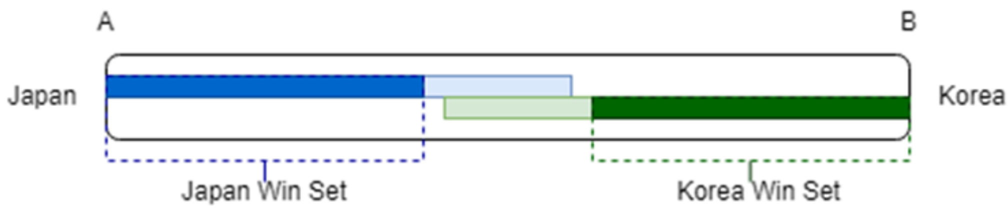


Figure 6.2: The "Win Sets"

Next, we will simplify this model into an extensive form game. Figure 3 expressed level 1 as an extensive form dynamic game. The first player is South Korea, who can choose to reach an agreement with Japan by playing negotiate or by playing escalate. If *escalate* is played, Japan can respond by either choosing to reach a new agreement with *negotiate* or furthering the dispute with *retaliate*.

Each of the possible outcomes has a payoff represented by a variable. If South Korea chooses to negotiate as their opening move, we reach a payoff closer to Japan's preferred preferences in the agreement set of the previous model. Likewise, if South Korea *escalates* and Japan decides to *negotiate*, we end up with a payoff closer to Korea's preferences. If South Korea *escalates* and Japan decides to

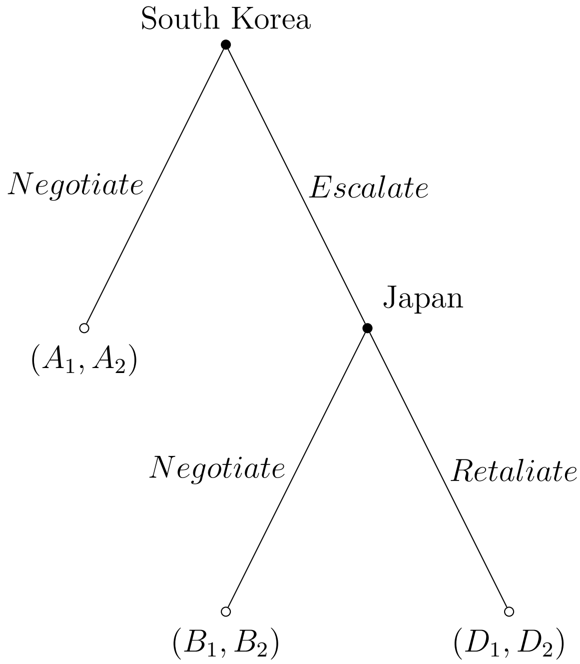


Figure 6.3: Simple Model

retaliate, the players receive the outcome D1 and D2, which represents the utility of negotiation breakdown and a continued trade dispute.

Both players prefer to reach an agreement closer to their own position: A for Japan and B for Korea. They also prefer any agreement over no agreement. Korea's preferences are thus:$B_1 > A_1 > D_1$, and Japan's preferences are: $A_2 > B_2 > D_2$.

We assume complete information, meaning the utility and strategies are common knowledge to both parties.

Using backwards induction, we see that Japan has the same credibility problem as in figure 5.1. Japan's payoff of choosing *Negotiate* is larger than choosing *retaliate*. *Retaliate* is therefore strictly dominated and will not be played. South Korea then has a choice between *Negotiate* giving them A1 or *Escalate* giving them B1. Since South Korea prefers B1 over A1, the sub-game perfect equilibrium thus becomes:

$SPE < Escalate, Negotiate >$

This outcome is Pareto optimal since South Korea receives their preferred outcome.

Next, I will consider a model where I include the constrains of domestic factors on Japan's utility, represented by the variable C. Further we assume that C is unknown to South Korea making this a game of imperfect information. In order to model this, I construct a screening game where South Korea is uncertain of the value of C. On the left side C is larger than Japan's payoff of $B_2 - D_2$ and will therefore change Japan's preferences to prefer Retaliate over Negotiate. On the right side C is less than $B_2 - D_2$ and will therefore functionally be the same game as the previous model. South Korea believes that C is greater than $B2 - D2$ with probability p and less than $B2 - D2$ with probability $1 - p$. We will call these sides large C and small C for simplicity.

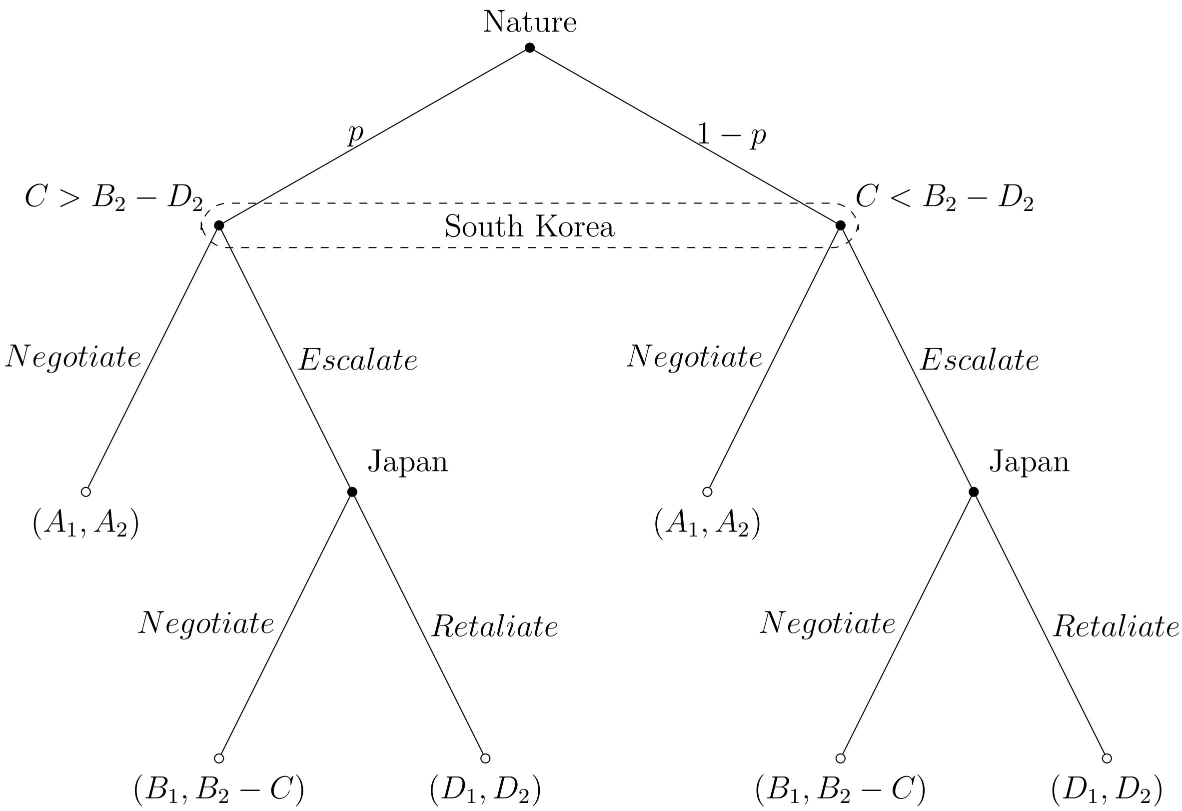


Figure 6.4: Game with imperfect information

Japan's strategy is as follows: With a large C choose retaliate, and with a small C choose negotiate. South Korea will therefore prefer to Negotiate if C is large and escalate if C is small. In order to find South Korea's opening move we need to calculate the payoffs on each side multiplying with the probability of C's value:

$$U(Escalate) = p(D1) + (1 - p)(B1) > A1$$

Simplifying gives us the following:

$p > \frac{A_1 - B_1}{D_1 - B_1}$

The Perfect Bayesian Equilibrium is thus:

- If $p > (A_1 - B_1)/(D_1 - B_1)$ South Korea negotiates
- If $p < (A_1 - B_1)/(D_1 - B_1)$ South Korea escalates
- Japan retaliates if C is large and negotiates if C is small
- South Korea's belief is that C is greater than $B_2 - D_2$ with probability p

6.2 Results and Implications

The first figures show how different the two levels operate. While outcomes seem irrational from one perspective, by examining the payoffs from the domestic level we can see why an agreement was not produced. The second pair of models explains how domestic factors can lead to negotiation breakdown due to uncertain information. In a level 1 game between rational states, both states assume the other will avoid the costly outcome of negotiation breakdown. When we implement a domestic constraint factor, however, the other player is unsure of the other players preference. This game of imperfect information can then lead to seemingly sub-optimal outcomes from a level 1 perspective, but by examining the domestic payoff, we see that it is a result of players belief in the other players' type.

There are other methods of explaining the dispute without having to resort to two level analysis, such as considering a time factor through repeated games, or modeling relative gains. The advantages of using two-level games in this case are that we can more closely connect to prior research. Since much of the literature relies on domestic factors when discussing Japan-South Korea relations, using a framework that accounts the effects of the domestic level, makes it easier to compare and integrate the other research on this topic, while still being able to use game theoretical models that assume rationality.

Even if we go on to assume states as unitary actors in further games. Doing a preliminary analysis with two-levels can help expose the states' preferences giving more reliable solutions as they are based on payoffs closer to reality. (Midlarsky et al., 1994)

Chapter 7

Conclusion

7.1 Summary of Results

This thesis has examined the strategic motivations that led to the 2019 Japan–South Korea dispute, by representing the dispute as various models focusing on different aspects with different assumptions.

I first examined the dispute as both a dilemma of common aversions through the Game of Chicken model and as an instance of the Prisoner's Dilemma game. The models revealed the inherent challenges in resolving the dispute due to strategic incentives that favor escalation and unilateral gains. As one or both players had an incentive to deviate from negotiations, the equilibrium outcome resulted in a situation where it was difficult for both parties to credibly commit to resolving the conflict. I also examined potential methods to resolve the dispute. If the prisoner's dilemma is repeated an unknown amount of times, a tit-for-tat strategy for both players would eventually lead to the players being incentivized to cooperate.

Next I modeled the dispute as a sequential game in extensive form, both with and without perfect information. The principal findings suggest that Japan's actions may constitute an implicit threat, potentially shaping future interactions between the two states. In order to make their threats credible Japan would also have to follow through, should Korea choose to persist, but by doing so South Korea would be more likely to refrain in future interactions.

Finally Putnam's two-level game was considered in order to examine the domestic constraints placed upon the international negotiation. The initial model demonstrates the disparity in outcomes when viewed from different levels. Actions that appear irrational at one level can be understood as rational when considering domestic-level payoffs, explaining the lack of agreement in the dispute.

The subsequent model illustrates how domestic factors can contribute to the breakdown of negotiations due to imperfect information. In a basic game between rational states (level 1), both parties are expected to avoid costly outcomes. However, introducing a domestic constraint adds uncertainty about the other player's preferences. This uncertainty, a characteristic of games with imperfect information, can lead to outcomes that seem sub-optimal from the international perspective but are rational when considering domestic incentives and beliefs about the opponent's stance.

7.2 Concluding Remarks

The goal of the thesis has been twofold. First it has attempted to offer an alternative rational explanation for the dispute between the two states. In a field where cultural explanations dominate, often in the form of domestic issues being the driving force of action, this thesis has attempted to show that the classical assumptions of states as rational unitary entities is still applicable in this area. The second goal was to develop and test StratPy as a flexible tool geared toward political scientists that could aid in model analysis, as well as offering a convenient and easy to use method of exporting these models to latex.

While the often cited explanations such as the unresolved wartime past, and anti-Korean–Japanese sentiment are surely factors impeding progress between the states, this thesis provides a more structured framework where these notions are represented as contributing to an added audience cost (or a constraint) on a negotiators win set. This relationship goes the other way too, where instigating foreign disputes can be used as a way to distract the population from domestic issues. In other words, the cultural and nationalistic elements aren't an explanation of the dispute itself, but can be seen as another tool in an arsenal being used by the state to optimize its utility, either to secure votes for the next election, or to subdue domestic unrest.

The benefits of offering rational explanations are many. Years of nationalism and cultural problems is a vastly more difficult problem to solve, and is likely to be a slow grind towards a resolution. Coordinating to mutually beneficial outcomes or creating self-enforcing agreements is a much easier hurdle to overcome. Furthermore, a rational explanation is more generalizable to a more universal case of international disputes, and can therefore rely on a larger pool of research, both in further analysis and for reaching solutions.

7.3 Further Research

Due to the limited scope of this thesis, only the initial interactions of the dispute were modeled. For further research it would be interesting to expand the time-frame and consider more of the back-and-forth interactions that took place. Although this would obviously lead to increased complexity of the model, it could provide further insight into how the players' strategies developed during the dispute. Furthermore, as mentioned in section 3.3.1, many actors were purposefully left out of the models. Exploring the effects of other key players such as the United States and China on the proceedings of the dispute might help contribute to a more nuanced perspective giving producing further insights.

While outside the scope and limitations of this thesis, another approach that can be used in further research, and perhaps the most novel, is to further develop the game theoretical models through machine learning. Expected utility, as well as updating players preferences can be learned by feeding vast amounts of data into an ML model. Simulating the dispute using a two agent adversial reinforcement learning model, could further the predictive power of the rational framework. (Zhou et al., 2019)

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Appendix A

Python code

The following code was used to generate all the Game Theory models in this thesis, as well as calculating strategies and equilibria. The code is all written in Python using the StratPy library and is divided into one file per chapter.

A.1 Code for Chapter 4

```
from stratpy import *

output_dir = "figures/"

""" Figure 4.1 - Chicken Game """
# Creating a payout matrix
utility4_1 = [[(-1, -1), (-5, 1)],
              [(1, -5), (-10, -10)]]

# constucting the game
model4_1 = Game("Game of Chicken", utility=utility4_1)

# adding information on players
p1, p2 = model4_1.player[1], model4_1.player[2]
p1.name = "Japan"
p2.name = "South Korea"

# labeling the actions
action_set = ["Negotiate", "Escalate"]
p1.actions = action_set
p2.actions = action_set

# Getting information about the model
model4_1.summary()

# Exporting the model
model4_1.export_latex(3, output_dir + "4-1.tex")
```

```

""" Figure 4.2 - Prisoner's Dilemma """
# constructing utility variables
a1, a2, b1, b2, c1, c2, d1, d2 = (Variable("-1"), Variable("-1"), Variable("-5 - C"), Variable("1"),
                                  Variable("1"), Variable("-5 - C"), Variable("-10"), Variable("-10"))

# The players' preferences
c1 > a1 > d1 > b1  # player 1
b2 > a2 > d2 > c2  # player 2

# Creating a payout matrix (this time with variables)
vars4_2= [[(a1, a2), (b1, b2)],
           [(c1, c2), (d1, d2)]]

# constucting the game
model4_2 = Game("Prisoner's Dilemma", variable=vars4_2)

# adding information on players
p1, p2 = model4_2.player[1], model4_2.player[2]
p1.name = "Japan"
p2.name = "South Korea"

# labeling the actions
p1.actions = action_set
p2.actions = action_set

# Getting information about the model
model4_2.summary()

# Exporting the model
model4_2.export_latex(3, output_dir + "4-2.tex")

""" Figure 4.2 - Zero-Sum Game """
# constructing utility variables
zero, M, minus_M = Variable("0"), Variable("M"), Variable("-M")

# The players' preferences
M > zero > minus_M

# Creating a payout matrix (this time with variables)
vars4_3 = [[(zero, zero), (minus_M, M)],
           [(M, minus_M), (zero, zero)]]

# constucting the game
model4_3 = Game("Zero-Sum Game", variable=vars4_3)

# adding information on players
p1, p2 = model4_3.player[1], model4_3.player[2]
p1.name = "Japan"
p2.name = "South Korea"

# labeling the actions
p1.actions = action_set
p2.actions = action_set

```

```
# Getting information about the model
model4_3.summary()

# Exporting the model
model4_3.export_latex(3, output_dir + "4-3.tex")
```

A.2 Code for Chapter 5

```
from stratpy import *

output_dir = "figures/"

# Creating the game models for Chapter 5

# Model 1a
game5_1a = Game(title="Model 1a", player_num=2)

# Creating the players
p1, p2 = game5_1a.player[1], game5_1a.player[2]
p1.name = "South Korea"
p2.name = "Japan"

# Setting up the players utility
s1, s2 = Variable("S_1"), Variable("S_2")
d1, d2 = Variable("D_1"), Variable("D_2")
s1_g, s2_a = Variable("S_1 + G"), Variable("S_2 - A")

# setting the players preferences
s1_g > s1 > d1
s2 > s2_a > d2

# Adding nodes
(game5_1a + Decision(p1, "Refrain", variable=(s1, s2))
          + (Decision(p1, "Persist") + Decision(p2, "Punish", variable=(d1, d2)) +
                                        Decision(p2, "Ignore", variable=(s1_g, s2_a
    ))))

game5_1a.summary()

game5_1a.export_latex(1.5, output_dir + "5-1a.tex")

# Model 1b
game5_1b = Game(title="Model 1b", player_num=2)

# Creating the players
p1, p2 = game5_1b.player[1], game5_1b.player[2]
p1.name = "South Korea"
p2.name = "Japan"

# Adding nodes to the tree
(game5_1b + Decision(p1, "Refrain", utility=(3, 3))
 + (Decision(p1, "Persist") + Decision(p2, "Punish", utility=(1, 1)) +
    Decision(p2, "Ignore", utility=(4, 2))))

```

```
game5_1b.summary()

game5_1b.export_latex(1.5, output_dir + "5-1b.tex")

# Model for 5-2 - with incomplete information

game5_2 = Game("Incomplete Information")
nature, p1, p2 =game5_2.player[0], game5_2.player[1], game5_2.player[2]
p1.name = "South Korea"
p2.name = "Japan"

# new information set
info_set = 1

# actions for nature
# the probabalistic action causes the information set 1
nature_p = Decision(nature, "p", information_set=info_set)
nature_1_p = Decision(nature, "1 - p", information_set=info_set)

# actions for South Korea
a_refrain = Decision(p1, "Refrain", variable=(s1, s2))
a_persist = Decision(p1, "Refrain")
b_refrain = Decision(p1, "Refrain", variable=(s1, s2))
b_persist = Decision(p1, "Refrain")

# actions for Japan
a_punish = Decision(p2, "Punish", variable=(d1, d2))
b_punish = Decision(p2, "Punish", variable=(d1, d2))
b_ignore = Decision(p2, "Ignore", variable=(s1_g, s2_a))

# adding nodes to tree structure
game5_2 + nature_p + nature_1_p
# A side
nature_p + a_refrain + a_persist
a_persist + a_punish
# B side
nature_1_p + b_refrain + b_persist
b_persist + b_punish + b_ignore

game5_2.summary()

# Export the game as latex
game5_2.export_latex(2.5, output_dir + "5-2.tex")
```

A.3 Code for Chapter 6

```
from stratpy import *

output_dir = "figures/"

# Creating the game models for Chapter 6

# Figure 6-3
game6_3 = Game(title="Figure 6.3")
```

```
# Creating the players
p1, p2 = game6_3.player[1], game6_3.player[2]
p1.name = "South Korea"
p2.name = "Japan"

# Setting up the players utility
a1, a2 = Variable("A_1"), Variable("A_2")
b1, b2 = Variable("B_1"), Variable("B_2")
d1, d2 = Variable("D_1"), Variable("D_2")

# setting the players preferences
b1 > a1 > d1
a2 > b2 > d2

# Adding nodes
(game6_3 + Decision(p1, "Negotiate", variable=(a1, a2))
 + (Decision(p1, "Escalate") + Decision(p2, "Negotiate", variable=(b1, b2)) +
    Decision(p2, "Retaliate", variable=(d1, d2))))

game6_3.summary()

game6_3.export_latex(2.5, output_dir + "6-3.tex")

# Figure 6-4 - with incomplete information
game6_4 = Game(title="Figure 6.4")

nature, p1, p2 = game6_4.player[0], game6_4.player[1], game6_4.player[2]
p1.name = "South Korea"
p2.name = "Japan"

# new payoffs for incomplete game
b2_c = Variable("B_2 - C")

# setting up nature and the resulting information set
info_set = 1
nature_p = Decision(nature, "p", information_set=info_set)
nature_1_p = Decision(nature, "1 - p", information_set=info_set)

# actions for South Korea
sk_a_negotiate = Decision(p1, "Negotiate", variable=(a1, a2))
sk_a_escalate = Decision(p1, "Escalate")
sk_b_negotiate = Decision(p1, "Negotiate", variable=(a1, a2))
sk_b_escalate = Decision(p1, "Escalate")

# actions for Japan
j_a_negotiate = Decision(p2, "Negotiate", variable=(b1, b2_c))
j_a_retaliate = Decision(p2, "Retaliate", variable=(d1, d2))
j_b_negotiate = Decision(p2, "Negotiate", variable=(b1, b2_c))
j_b_retaliate = Decision(p2, "Retaliate", variable=(d1, d2))

# adding nodes to tree structure
game6_4 + nature_p + nature_1_p
# when C is large
nature_p + sk_a_negotiate + sk_a_escalate
sk_a_escalate + j_a_negotiate + j_a_retaliate
# when C is small
```

```
nature_1_p + sk_b_negotiate + sk_b_escalate
sk_b_escalate + j_b_negotiate + j_a_retaliate

game6_4.summary()

game6_4.export_latex(2.4, output_dir + "6-4.tex")
```

Appendix B

StratPy Source Code

The source code for StratPy is too large to include in the appendix but can be found publicly available in the following GitHub repository: https://github.com/fredrikofstad/stratpy/

The following guide is provided on how to maneuver the repository, to access relevant files.

The source rust code is found in the *src* directory and is divided by module. The tree module includes the basic structure of a game tree, including the *Game* class itself and representations for *nodes*, *players*, and *utility*. The algorithm module contains the solution strategies and other analytical tools that can be performed on the model. Logic involving printing or generating the models as well as exporting to latex or DOT is contained within the *export* module.

The unit tests are contained within the Rust files themselves tagged with the "#[cfg(test)]" annotation. The integration tests are located in the test directory in the root of the repository. This directory contains python files that test different aspects of the library.

Deployment tests are located in the *.github/workflows* directory, and is automatically called by GitHub for every commit pushed to it.

The library can either be compiled from source by first cloning the repository, installing the dependencies in the *requirements.txt* file and finally running:

```
> maturin develop
```

in the terminal, or more simply by downloading and installing the public release by running the following command in a terminal:

```
> pip install stratpy
```

Further documentation for using the library and contributing to the library is contained in the following website: http://stratpy.ofstad.co/