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Game Theory Applications In The Airbus-Boeing Dispute

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Abstract
This study examines the intricate trade dispute between Airbus and Boeing which took place from the late 1970s all the way till 2021. By using game theory tools including Nash equilibrium, mixed strategies, Stackelberg competition and credible threats, I can explore the strategic trade decisions, such as tariffs, subsidies and complaints to the WTO, taken by each player and how this affects the overall competitiveness and the health of the LCA sector. Each of these games use data from the real world in order to effectively depict the outcomes that could have arisen and those that actually happened. The key findings were able to illustrate how although some of the theoretical economic ideologies were used, the real life decisions still deviated from the stable outcomes due to external pressures and factors. The results provide us a more intricate understanding of the trade world and the economic environment of the LCA industry.

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I. Introduction

During the 1970s and late 1960s, the US dominated the large corporate aircraft (LCA) sector with firms like Boeing, McDonnell Douglas, and Lockheed. These companies were industry giants, leaving little room for other firms to enter the market. However, in 1969 arose Airbus, a consortium between different European Nations. This up and coming firm, although with great products and ideas, seemed small and incomparable to the giants of the US. Thus, they received significant help from the European governments which brought problems of competition for Airbus. Airbus received a large sum of governmental financial support to help the firm grow and be on competing grounds with the rest of the industry. The US saw this as an anti-competitive measure, as excessive government support reduces the costs that Airbus have to bear and such a facility was not available to the US (Hossain, 2023). Negotiations started between the US and EU to resolve this, and in 1992 an agreement was signed between the European Union and the United States of America. This agreement laid down stringent terms for both the entities, ensuring that the market got a chance to operate freely and encouraged healthy competition. The terms were: a ceiling on the amount of subsidy/loan, at 33% of the total development costs with a maximum tenure of 17 years and an interest rate greater than or equal to the cost of borrowing for the government; the amount of indirect support (research and development grants) to be capped at 3% of the LCA sector's annual turnover (EU-US Agreement on Large Civil Aircraft 1992: key facts and figures, 2004). This 1992 agreement seemed to have settled the earlier dispute between the two nations, however both nations seemed to have lost an external means of support. Airbus no longer could avail governmental financial support to help establish themselves in the Boeing dominated market and Boeing no longer was able to receive as much support viz-a-viz NASA or other military programmes.

However, the agreement that once seemed to be the end of this dispute, was merely just a temporary pause in the trade dispute. What followed next was one of the largest trade wars in history, going as far as involving the World Trade Organisation. Airbus saw massive growth in market share post the 1992 agreement, starting at 30% of total market share in 1992, and reaching close to 50% in 2003. Airbus's main growth is accredited to a couple of factors. Primarily, the firm was able to create a wide product range including several passenger, freighter and corporate planes. Furthermore, the firm also invested in and developed their technological aspects such as the fly-by-wire technology which gave them a significant competitive edge in terms of safety and efficiency. These developments were upheld by the financial support that was provided to Airbus. They edged past Boeing in market share and ended up selling more new aircrafts in 2003. As competitive pressures rose for Boeing, the US further scrutinised the practices of Airbus and found that Airbus was not abiding by the terms of the 1992 agreement. The US government alleged that Airbus had received close to $15 billion worth of subsidies and a total of $40 billion in aid since inception, which strongly went against the terms of the 1992 agreement (Carbaugh and Olienyk, 2004). Complaints were immediately filed to the WTO and the US withdrew from the agreement. In retaliation, the European Union also filed complaints to the WTO about an alleged $23 billion in tax incentives and infrastructure subsidies that Boeing had availed, that once again went against the terms of the 1992 trade agreement. Following this, unravelled the biggest trade dispute involving other protectionist measures that the two entities imposed on each other. This dispute finally cooled off in 2021 with both parties agreeing to remove protectionist measures and reach a better agreement through negotiations.

The commercial aviation industry has existed as a duopoly for the most part since this agreement (Sprague, 2019). The other two aircraft manufacturers, McDonnell Douglas and Lockheed, were out competed by Airbus. This global duopoly meant that there would be high barriers to entry, due to high setup costs and regulatory requirements. Both of these firms are targeting the same customer base, including commercial airlines, governments and militaries.

Moving to our research question, I implement the concepts of game theory to strategically analyse how both of the players interacted with each other. Using a series of tools such as Nash equilibrium, mixed strategies equilibrium, credible threats, Stackelberg competition and bargaining & negotiations, I can create a structured framework to analyse how each strategy impacted the other party. It allows us to work out the mindset of each of the players, the US and the EU, with a deeper understanding of how they reached the strategies they implemented. It also creates a path to find the other possible outcomes that could have been reached and understand how such a dispute could be avoided in the future.

Lastly, to ensure that I am able to maintain comparability between the two players in the games I set up, I have found similar counterparts of aircraft models between the two companies. This includes wide body aircrafts such as the Boeing 747 and Airbus A380.

II. Literature Review

In this section of the paper I will start with an examination of other case studies of trade disputes and how these other studies implemented game theory into their analysis. This includes case studies of trade disputes such as the US-China trade war or a trade dispute between the US and Saudi. This examination will allow us to gain insights into how other trade disputes have been analysed and what methods were used to reach effective conclusions. Following this I will explore research literature specific to the Airbus-Boeing trade dispute to understand the different strategies at play, the real world negotiations and the outcomes of the different strategies deployed. Lastly, I will briefly overview the characteristics of the aerospace industry to lay a foundation for the games that will be setup in the next section.

Game theory is a key mathematical tool that has been used for decades to unravel and understand the strategic behaviour between two or more parties. When exploring matters such as international trade, it has given noteworthy insight to researchers and policy makers around the world, as to how two opposing parties think and act. It allows us to analyse the outcomes that were reached and the outcomes that could have been reached.

The first work analysed is a study by Khurana (2022) on the US-China trade war. The US-China trade war started in late 2017, when the US faced concerns about the effect of imported Chinese washing machines and solar panels on their domestic industries. By 2018 this escalated dramatically as both countries sent threats to each other and their economies too faced adverse impacts. Both countries saw billions of dollars' worth of drops in the value of imports, reductions in investment, and massive drops in GDP. The key strategy that both the US and China had implemented was tariffs, as the US imposed them first and China followed suit by imposing retaliatory tariffs. Furthermore, China had also provided tax breaks and financial support to local firms as a form of protectionism (Liu and Woo, 2018).

This study utilised a modified version of the prisoner's dilemma with an embedded snowdrift game in the mutual defection box. A snowdrift game is similar to prisoner's dilemma, however in a snowdrift game the mutual defection box is much more destructive as both players lose significantly more.

Figure 2.1 Payoff Matrix (Khurana, 2022)

<table>
<tr><td>China →
United States ↓</td><td>Cooperate</td><td>Defect</td></tr>
<tr><td>Cooperate</td><td>(4,4)</td><td>(0,3)</td></tr>
<tr><td>Defect</td><td>(3,0)</td><td><table><tr><td>China →
US ↓</td><td>Turn</td><td>Stay</td></tr><tr><td>Turn</td><td>(0,0)</td><td>(-1,1)</td></tr><tr><td>Stay</td><td>(1,-1)</td><td>(-10,-10)</td></tr></table></td></tr>
</table>

Figure 1.1 displays a payoff matrix designed by the author of the paper, illustrates the situation between the two players. The payoff matrix is able to demonstrate the consequences that each player will face as a result of their strategic decisions. If both players cooperate with each other and reach a compromise where they don't impose any trade protection, then they are mutually benefitting as both players get a higher positive payoff. The next scenario is when one of the players defects. This implies that one of the players in the game is opposing the agreement to cooperate and they impose some form of trade protection. In the case of the US-China trade war it was tariffs. So if one of the nations defects and imposes a tariff, then it is likely to benefit much more than the other nation. In this case, the payoff ends up being 0 for the losing nation. However, a situation arises in which one nation expects the other to defect so they also defect. This is known as the Nash equilibrium, where both players choose to defect and as a result they both end up being worse off. In this specific payoff matrix, Khurana (2022) has created another payoff in the mutual defection box so that the players do not have to bear the consequences of the mutual defection. This payoff matrix is known as a snowdrift game, which is similar to the classical prisoner's dilemma, but the mutual defection box has extreme consequences. As the name suggests, the snowdrift game is about two skiers who are approaching each other. Now they have the option to turn and save themselves, or they can stay and risk colliding with each other. Now if they collide, then they both lose significantly. This represented the situation between the US and China, where the initial matrix represents the decisions to impose tariffs on each other. And the subgame in the mutual defection box represents their decision to continue their aggressive tariff imposition. This model is accurately able to depict the different outcomes of the trade dispute between the US and China, also depicting the real-life outcome in the mutual defection box of the snowdrift game, as both of the countries lost billions of dollars in export value. Hence, it's useful in analysing the strategic interactions between Airbus and Boeing.

The next study by Roy et al., 2020, involves the application of sequential games in trade. The study analyses the trade dispute between the US and Saudi Arabia. This dispute was about the world price of crude oil. In 2014, the US put pressure on Saudi Arabia to reduce their production of crude oil so that prices would not drop too much. However, the oil minister of Saudi Arabia was able to convince the Organization of the Petroleum Exporting Countries (OPEC) to increase the output, enough to allow the prices of crude oil to fall around the world. Now this was done with one main incentive, which was to drive US oil producers out of the market (Council on Foreign Relations, n.d.). Based on this, the study designed a sequential game in which it created a series of strategic decisions that the US could take in response to the increase in production that Saudi Arabia took.

Roy et al. (2020) used the stackelberg model to show how the sequential movements unravelled. As Saudi Arabia was the first mover, they were assumed to raise production by 1 million barrels a day to around 12.974 million barrels a day. Based on this, the US is required to adjust its production levels to 5118255.017 barrels per day to maintain profit maximisation. This reflects the disadvantage that the US faces of being the follower in the sequential game and how Saudi Arabia gained a first mover's advantage (Roy et al., 2020). This was another key example of game theory concepts being used to analyse and model real world outcomes of strategic interactions between two international players. Since our study of Airbus and Boeing also involves a first mover it is useful for us to understand how Stackelberg competition was applied in this case.

Both of these case studies allow us to understand how tools such as prisoner's dilemma or stackelberg competition have been used in real life scenarios, hence it allows us to understand how I can use them.

Now moving on to the main crux of the trade dispute. I will understand how the trade dispute initially unravelled, post the 1992 agreement and what negotiations took place between the two countries. In 2004, the first claim that the United States government had made was a claim against the illegal provision of subsidies to Airbus by the European Union governments totalling to around $22 billion. They claimed that these subsidies, in the name of launch aid and infrastructure support, gave Airbus a significant competitive edge in this industry. Following suit, the European government filed a counter complaint to the WTO, in which they stated that the US government too has been granting Boeing illegal subsidies, totalling to $19 billion in tax breaks, military and NASA grants. Following this, in 2010 the WTO made a ruling that Airbus had received $15 billion in subsidies and they ruled that this significantly caused a competitive disadvantage for Boeing. Similarly, in 2011 it was ruled by the WTO that the US government had provided illegal subsidies, through tax breaks, military contracts and the department of defence, as they distort Airbus' competition.

However, in 2012-2014 both the US and EU aimed to make compromises with each other by adjusting the amount of subsidies that they each provide to each of their respective firms. In the following years, Boeing was still observed to receive illegal subsidies from the US government which was soon to be followed by retaliatory measures. In 2019, the WTO authorised the US government to impose $7.5 billion worth of tariffs as a retaliation to the subsidies, on quite a few goods including aeroplanes. A mini trade war was initiated as the EU was also authorised to impose $4 billion on a range of goods, once again including aeroplanes (Hossain, 2023). Lastly, in 2021 in a final effort to settle this temporary truces were introduced such that they settle the dispute for the short term (Leggett, 2021).

This timeline will allow us to comprehensively understand how the real life scenario unravelled with the two players and how they ended up forming their resolution.

III. Methodology

This section's primary aim is to explain the methods, i.e., the 5 key game theory tools that will be used and their pertinence to this research question.

The first tool we will use is the Prisoner's Dilemma and Nash equilibrium, a game theory tool that analyses the payoffs players receive from either cooperating or defecting from an agreement. This helps illustrate the stable outcomes that prevent any player from losing. Furthermore, this tool is essential in illustrating the stable outcomes that can be reached in order to ensure that none of the players are losing. Payoffs will be estimated from real world data and economic understanding of the outcomes.

Secondly, I will use a payoff matrix matrix to achieve the mixed strategy Nash equilibrium and solve for the dominant strategy equilibrium. This will be able to enhance our understanding of how different strategies work together, exemplifying the dilemma that Airbus or Boeing faced as they had to decide between different trade protectionist measures. The uncertainty and randomness that arises as a result of the mixed strategies, will also be modelled.

Next, I will employ a model of Stackelberg competition in which I will design a sequential game, similar to how it has played out in real life. Since Boeing/the US government was the first mover, a game will be designed in such a way that I am able to reflect the real life movements of each of the players and understand the thought process with which each player made a move. Calculus methods will be employed to find the optimum tariff rate for each country, thus cracking down their thought process.

The last tool that will be able to emulate the real life scenario is credible threats with a mathematical evaluation. I will discuss the different credible threats that were imposed, followed by a diagrammatic representation, viz-a-viz a decision tree, of the different outcomes that each of the players may have predicted to be credible. This will be followed by backward induction in which I work backwards, to find out how the threat was posed.

All of these models will be then compared to the data trends and real world outcomes to test the viability of these models. After which I will collate the results and form a reasonable conclusion. With this, I demonstrate either the real world outcome or a better possible outcome that they could have reached.

IV. Applications Of Game Theory

Prisoner's Dilemma and Nash Equilibrium

To begin the applications, I will start with the "Prisoner's Dilemma" in which I will create a payoff that is able to exhibit the different consequences encountered as a result of imposing different trade protectionist measures.

The first trade protectionist measure will be the provision of subsidies to each of their respective firms. Subsidies act as a trade protection, as they can give unfair competitive advantages to the subsidised firm, by facilitating lower average costs of production and translating into lower prices. This payoff matrix will be able to simulate the different payoffs that arise when Airbus or Boeing decides to subsidise or to refrain from subsidisation. The two players in this game are Airbus and Boeing, who take the decision of whether or not to avail subsidies.

	Airbus Refrains	Airbus Avails Subsidies
Boeing Refrains	(4,4)	(5,1)
Boeing Avails Subsidies	(1,5)	(3,3)

Figure 4.1 Airbus vs Boeing Subsidies Payoff Matrix

For Figure 4.1, each of the payoffs are assigned, in the format (Airbus, Boeing). The top left box is a situation in which both of the players refrain from the subsidy, as they mutually cooperate, allowing the market to operate freely. Both of the firms are able to earn a higher payoff of 4 each, as they engage in competitive practices. This promotes cost efficiency, higher productivity and ensures that the firm is able to maintain practices that can be sustained in the long-term. Thus, they both receive a moderately high payoff of 4. Next, if one of the firms defect from the mutual cooperation agreement and choose to receive subsidies from the government this is likely to distort the competition and lead to a disparity in the payoffs. Suppose I examine the top right box. I observe that Airbus receives a significantly larger payoff of 5. As Airbus possesses governmental support for their production, they are able to receive aid that Boeing does not have access to. This could give them Airbus and the European Union an absolute advantage over Boeing and the USA. Similarly, if Boeing decides to avail subsidies for the production of aeroplanes, they will be gaining an unfair competitive advantage over Airbus for the aforementioned reasons. However, accounting for the non-cooperative nature of this game, there is a possibility that both of the players end availing government subsidies and this would lead to a situation known as the Nash equilibrium. Nash equilibrium is a steady state in which both of the players have no incentive to deviate from their current strategy as they don't foresee benefits with other strategies (www.sciencedirect.com, n.d.). Both of the players expect the other player to avail subsidies and in doing so they both end up defecting from the original agreement of a free market, and once they end up pursuing the strategy to avail a subsidy, it would be inadvisable to deviate from that strategy, to avoid the payoff of 1. Even though they both end up receiving financial support from the government they still would end up with a lower payoff for a couple reasons. Firstly, as both the players are subsidised, this will result in lower prices from both the firms. Oftentimes, these lower prices end up fueling price wars, in which both of the firms aim to undercut each other's prices which could end up adversely impacting the profit margins of either firm. In more specific terms, our trade dispute observed extended legal battles lasting decades in which both firms face high magnitudes of litigation costs. Further, this specific mutual defection also opened up the path for a trade war, in which I saw that both the EU and the US imposed tariffs on many products including aeroplanes. Thus, both of them are worse off even though they receive governmental support.

Another important aspect that we must inspect is the existence of dominant strategies. A dominant strategy is a strategy that a player will pursue, regardless of the other player's strategy, as they gain the highest possible payoff. So in this case, Boeing is likely to pursue the strategy of availing subsidies, even if Airbus chooses to do so. Since Boeing receives a lower payoff whilst refraining, regardless of Airbus' decision (as 5>4 and 3>1), they are likely to avail subsidies. Similarly, Airbus too is likely to opt to avail subsidies as they find higher payoffs in either scenario (as 5>4 and 3>1). This exhibits how both of the players have a stronger incentive to pursue the strategy of availing subsidies, opposed to refraining.

Mixed Strategies

A small-scale trade war was observed between the EU and the US as a result of this trade dispute, in which they imposed tariffs on billions of dollars worth of goods, including aircrafts. However, the pure strategy Nash equilibrium as displayed above is only able to simulate a one-off condition, in which the player definitively picks either choice. However, in real life there are probabilities assigned to each of these, according to the circumstances. When the two players, the EU and the US, decided to impose tariffs, they must have come across a dilemma. It is likely that they calculated the chances of the other nation imposing retaliatory tariffs, so there is a certain probability of them imposing these tariffs. That probability can be calculated. The two players in this game are the EU and the US, who play on behalf of Airbus and Boeing.

Definitions of the Strategies:

T_B^H - High Tariff Boeing

T_B^L - Low Tariff Boeing

T_A^H - High Tariff Airbus

T_A^L - Low Tariff Airbus

	T_A^H	T_A^L
T_B^H	(-2,-2)	(5,2)
T_B^L	(2,5)	(4,4)

Figure 4.2 Airbus vs Boeing Tariff Mixed Strategies Payoff Matrix

For Figure 4.2, the payoffs are assigned (Boeing, Airbus). Starting off with the bottom right box which displays a situation in which both of the players cooperate with each other and refrain from increasing the rate of the tariff. In this situation they both impose comparatively lower tariffs, I observe that they both receive higher payoffs at 4 each. However, a situation can arise when one of the players decides to defect from mutual cooperation and chooses to impose a higher tariff. In the top right box I observe that Boeing has imposed a higher tariff. This higher tariff imposed creates a significant competitive boost for Boeing. As they impose a tariff on European imports, the price of these goods increases causing a contraction in demand, a significant hindrance in the sales revenue of European goods including aircraft by Airbus, and adversely impacts the market share of Airbus in the LCA market. A symmetrically opposite situation arises when the EU decides to impose a tariff on American goods, including aircrafts. The price of American imports in the EU will rise, causing a contraction in demand, a fall in the sales revenue of American goods including aircraft by Boeing, and a fall in their market share.

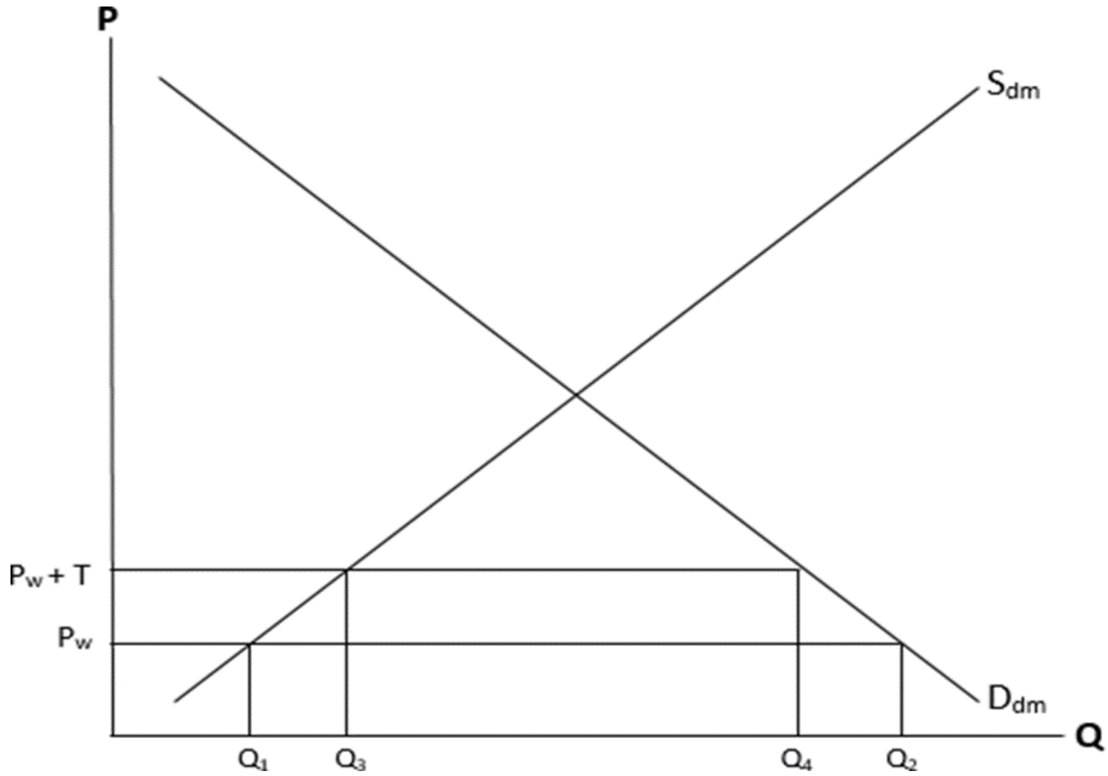

Figure 4.3 Imposition of Tariff Diagram

Figure 4.3 is able to represent the effect of imposing a tariff on the quantity demanded of European/American imports. The original market operates at price P_w, which is the world price. And at this price the quantity demanded in the domestic market is Q_2, whilst the quantity supplied exists at Q_1. The gap between the quantity supplied and demanded domestically is covered by imported goods. Once the tariff is imposed by either country the price rises to P_w + T. At this price the demand contracts from Q_2 to Q_4 and the quantity supplied extends from Q_1 to Q_3. As it can be observed, the gaps covered by imports have fallen as a result of this tariff, which indicates the country that gets imposed with a tariff will be worse off.

Lastly, there is a scenario of mutual defection. In this case both of the players, the EU and the US, anticipate that the other player will impose a tariff, thus, they impose a tariff. In this situation both of the players end up worse off as they become uncompetitive in the LCA market due to the high costs incurred due to tariffs and the lower sales revenue for either player. So both of them earn poor payoffs of -2 each. However, as I mentioned at the start of section 4.2, there is a certain probability that I come across when a mixed strategy Nash equilibrium is created. A probability is attached to each of the strategies that may be pursued.

pB: Probability that Boeing chooses T_B^H

$1 - pB$: Probability that Boeing chooses T_B^L

pA: Probability that Airbus chooses T_A^H

$1 - pA$: Probability that Airbus chooses T_A^L

Now, in order to display the Nash equilibrium an indifference equation must be solved. An indifference equation is used to compute the probability at which the player has no incentive to deviate from their current strategy according to the payoffs and the player is indifferent between both the strategies. The indifference occurs when the payoffs of the high and low tariff strategy are equal.

Expected Payoff of Airbus = E_A

$E_A(T_A^H) = pB(-2) + (1 - pB)(5)$

$E_A(T_A^L) = pB(2) + (1 - pB)(4)$

Solving for pB:

$pB(-2) + (1 - pB)(5) = pB(2) + (1 - pB)(4)$

$-2pB + 5 - 5pB = 2pB + 4 - 4pB$

$-5pB = -1$

$pB = \frac{1}{5}$ $or\ 0.2$

Expected Payoff of Boeing = E_B

$E_B(T_B^H) = pA(-2) + (1 - pA)(5)$

$E_B(T_B^L) = pA(2) + (1 - pA)(4)$

Solving for pA:

$pA(-2) + (1 - pA)(5) = pA(2) + (1 - pA)(4)$

$-2pA + 5 - 5pA = 2pA + 4 - 4pA$

$-5pA = -1$

$pA = \frac{1}{5}$ $or\ 0.2$

According to the indifference equation which I have solved, it can be determined that the mixed strategy Nash equilibrium occurs when the probability of imposing tariffs is 0.2 or 20%. The players are indifferent to choosing either strategy due to the parity in their payoffs. Thus, the probability of imposing a high tariff rate is relatively low at 0.2 for either of the players, as they aim to earn a higher payoff, which is only possible when they mutually cooperate and impose a lower tariff on their products. The mixed strategy Nash equilibrium is able to display the probability with which each of the players makes their decision, thus proving that the players may not already proceed with a pure strategy in mind.

Stackelberg Competition Model

An important point to note about this trade dispute was its sequential nature, in which one player followed the other one's move. When the US government initially filed a report to the WTO about the illegal subsidisation of Airbus, the EU retaliated with its own complaint to the WTO. They followed each other in the impositions of tariffs as well, once again with the US as the first mover and the EU following suit. Using the Stackelberg competition model, it can be analysed how Boeing decides its production quantity, as the first mover, whilst taking into account the anticipated response of Airbus. This sequential process will be examined under the constraints of the tariffs imposed by either country. In this model, the leader, Boeing, decides its production quantity first, dependent on Airbus, the follower. Airbus is likely to then observe Boeing's production quantity and formulate its optimal response. The Stackelberg equilibrium is reached when both of the firms reach an optimum output, under the tariff constraints, such that their profit is maximised.

I start by defining each of the equations:

Price Function:

$P(Q) = a - b(QB + QA)$, where a and b are arbitrary constants, which are for the maximum market price and the price elasticity respectively, and QA and QB are the quantities produced by Airbus and Boeing respectively.

Cost Functions per unit:

Boeing: $CB(QB) = cB \times QB$, where cB is Boeing's marginal cost.

Airbus: $CA(QA) = cA \times QA$, where cA is Airbus' marginal cost.

Tariffs per unit:

Boeing: TB, the tariff that Boeing faces.

Airbus: TA, the tariff that Airbus faces.

Profit Functions:
Boeing: $\pi B = (a - b(QB + QA)) \times QB - cB \times QB - TB \times QB$
Airbus: $\pi A = (a - b(QB + QA)) \times QA - cA \times QA - TA \times QA$

The steps of this sequential process:

1. Before finding Boeing's optimum production point, Airbus' optimum production point has to be found, as Boeing will use that in response. Thus, I can differentiate the Airbus' profit function with respect to QA and set it to 0. This gives us the optimum quantity that Airbus needs to produce to maximise their profits.
$\frac{d\pi A}{dQA} = \frac{d}{dQA}[(a - b(QB + QA)) \times QA - cA \times QA - TA \times QA] = 0$

$\frac{d\pi A}{dQA} = a - bQB - 2bQA - cA - TA = 0$

2. I now rearrange to find QA:
$QA = \frac{a-bQB-cA-TA}{2b}$
Hence, I have derived Airbus' best response function.

3. Now this anticipated response of Airbus is inputted into Boeing's profit function, as Boeing is likely to use this anticipated response in order to maximise their profitability.
$\pi B = (a - b(QB + \frac{a-bQB-cA-TA}{2b})) \times QB - cB \times QB - TB \times QB$
$\pi B = (a - bQB - \frac{a-bQB-cA-TA}{2}) \times QB - cB \times QB - TB \times QB$
$\pi B = (\frac{a-bQB+cA+TA}{2})QB - cBQB - TBQB$

4. The next step is to find the optimum quantity produced for Boeing by differentiating πB with respect to QB and setting it to 0.
$\frac{d\pi B}{dQB} = \frac{d}{dQB}[(\frac{a-bQB+cA+TA}{2})QB - cBQB - TBQB] = 0$
$\frac{1}{2} \times (a - 2bQB + cA + TA) - cB - TB = 0$

5. Now I rearrange to find QB:
$a - 2bQB + cA + TA = 2(cB + TB)$
$QB = \frac{a+cA+TA-2(cB+TB)}{2b}$

This model be tested using values that somewhat resonate with the real world scenario:

Tariff values on the LCA industry by both players were valued at 15% of the aircraft price. This is functioned as:
$TB = 0.15 \times PB \text{ or } TA = 0.15 \times PA$ (European Commission - European Commission, n.d.).
Accounting the prices of Airbus A380s and Boeing 747s ranging between \$200 million to \$400 million on the specifics, I take an average value at approximately \$300 million. So the tariff value for either player comes out to be approximately \$45 million per aircraft.

The arbitrary values a and b are valued at:
$a = \$150\ million$, as this is the maximum that could be charged for an aeroplane considering no competition. Whereas in real duopolistic competition it ranges from around \$80 million-\$120 million (SkyTough, n.d.).
$b = \$0.1\ million$. This value is able to show the small elasticity of demand in this market, due to the duopolistic nature of this market.

The marginal costs are valued at:
Boeing: $cB = \$50\ million$ (Boeing.com, 2015)
Airbus: $cA = \$45\ million$, as Airbus has shown higher production efficiencies. (Oestergaard, 2024)

If I input these values into our functions of QA and QB I arrive at:
$QB = \frac{150+45+45+-2(50+45)}{2\times0.1} = 250\ units$

$QA = \frac{150 - 0.1 \times 250 - 45 - 45}{2 \times 0.1} = 175 \, units$

This model is accurately able to depict how the first mover's advantage of Boeing/the US is able to coerce Airbus into an unfavourable situation, such that Airbus has to lower or adjust their production levels in order to still maintain their profitability. This lower production level of Airbus can possibly cause them to have lower market share and or not be able to supply as many aircrafts as they initially wanted to. However, the imposition of tariffs by Boeing, has forced them to have a lower production scale to ensure that their business stays profitable. In the analysis I will further break down how this may affect the future disputes between these or other parties.

Credible Threats

The last game theory application I will be examining is credible threats. Credible threats is a strategy used by players in such a dispute. These credible threats are certain convincing measures that either player threatens the other player with, in order to to get their way, else threatening negative repercussions. In the case of the Airbus-Boeing dispute there are two main types of credible threats that took place. The most prominent credible threat that took place was the imposition of tariffs. Initiated by the US and then followed by the EU, these threats eventually were carried out. The other main threat was the complaint to the WTO about the illegal subsidisation (Chanda, 2011). The threat behind this was the potential retaliatory measures that the US would carry out, such as, tariffs, if the EU did not agree to curb the subsidisation of Airbus. I designed a decision tree that was able to model the outcomes that would take place if the US took a decision to file a complaint or not. Payoffs are modelled to show a tangible outcome that takes place as a decision is made. And lastly backwards induction will be employed to explain the rationale behind the credible threat imposed by the US on the EU.

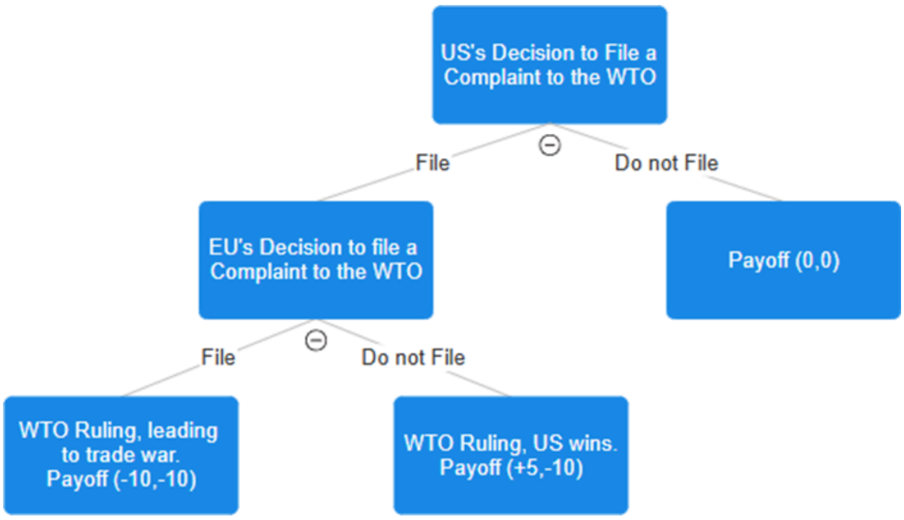

Figure 4.4 Decision Tree Model of Credible Threats of WTO Complaints

The payoffs have been assigned in the format of (US, EU). Initially, the US has the option of filing a complaint against the illegal subsidisation of Airbus to the WTO or not file. If the US chose not to file a complaint, they would have experienced a status quo, which is when neither player takes action and things remain as they were before the dispute. The payoff of this is (0,0) as both of the players do not see any changes in the payoffs that they receive. However, if they do choose to file a complaint, then I arrive at the next decision. Now, similar to the US, the EU also faces a decision of whether to file a complaint, or in this case a counter complaint. If they do choose to file a counter complaint, this is likely to lead to an escalation of the trade dispute. Thus, both of the players would lose, leading to a payoff of (-10,-10). However, if the EU chooses not to file a complaint, it would mean that the WTO ruling would be in favour of the US. The US would have a positive payoff as they may be given permission to retaliate, whilst the EU will have a negative payoff as they bear the financial consequences of losing this case.

The EU is likely to anticipate the high costs that will be incurred if they file a counter complaint, and they foresee the lower loss—of -5 instead of -10—if they do not file a complaint so they are more likely to not file a complaint. By predicting that the EU will not complain, the US is likely to file a complaint as they predict a competitive advantage over the EU when the WTO rules in favour of them. The threat of the escalation leads is what causes the players to back off, as they understand the losses that could occur. Even the small probability of losing, -10 each, influences the strategic behaviour of the US and the EU.

V. Results & Discussion

All 4 of the models that I have designed and implemented were able to give us results that are coherent with economic principles and overall benefit maximisation. Our aim was to analyse the Airbus-Boeing trade dispute through the lens of game theory, and understand how their interactions took place using mathematical tools. I examined the impact of trade protectionist strategies such as tariffs, subsidies and legal complaints on the competitive landscape between the two players and used game theory tools to explore the other outcomes that could have arisen instead.

Beginning by interpreting the results of the pure strategy Nash equilibrium that I have setup, I observe the different payoffs that arise as a result of availing or refraining from subsidies. Our payoff matrix (Figure 4.1) was able to highlight how the Nash equilibrium arises as a result of mutual defection. Both the players, Airbus and Boeing, decide to avail subsidies according to the real world situation, which leads to a lower payoff. Even though both of them have the financial upholding from the government, as they both avail subsidies, it creates a harsher and more difficult competitive landscape for either players. The model is successfully able to reflect how the firms reduced prices and ended up in a retaliatory tariff war. Even though the subsidies appear to benefit either firm in the short term by easing up their costs of production, in the long run they risk experiencing over-dependence on the government and complacency. This complacency is especially harmful in an industry such as the LCA industry due to the need for technological innovation and efficiency. However, since they receive subsidies, they may lose the incentive or the motivation to develop innovative or cutting edge technology, as they are backed by the government and do not risk a negative return on investment. I can observe from Figure 4.1 that if they both refrain from the usage of subsidies, they have a relatively higher payoff of (4,4) which indicates that they are likely to see more benefits without subsidies. They would be able to avoid this saga—spanning over two decades—that massively affected both of the firms as they both incurred massive legal costs and lost revenue from the tariff imposition. Not to mention the damage that took place on their brand image. In terms of policy implications, the governments and other official bodies may need to be stricter in terms of their monitoring and regulations. They may need to set more rigid rules in terms of the support that a firm is allowed to leverage from the government. Even though the government aims to support their own strategic industries, they must make sure that this support does not end up distorting the competitive landscape. Furthermore, these subsidies could be better designed. Instead of providing direct financial grants or tax breaks, the government could seek to restrict their grants to small-scale development and research grants, such that it promotes technological advancement rather than large-scale trade disputes.

Another important facet of our Nash equilibrium was the dominant strategy equilibrium, as we figured out that both of the firms had a strong incentive to pursue the strategy of availing subsidies, rather than refraining to maintain the free market. This clearly reflects how the real world scenario played out, as both of the firms took advantage of subsidies rather than refraining, which eventually escalated into this 17 year long dispute. Both of the firms must have realised the repercussions of refraining as they would have a relatively lower payoff than if they availed, thus they must have ended up with such a decision. This is an important implication for policy makers as they must incorporate the dominant strategy when they craft policies against the trade disputes. They must try to lower the benefit that the firms receive from the subsidy, increase the interest rate at which loans are provided to the firms and lower the term of the loans. This would ensure that the firms consider the option of refraining.

The next result obtained was the probability that either of the players imposed a tariff. According to our setup of the Stackelberg model and derivation of the profit maximising output, there was a 20% percent chance or a probability of 0.2 that either player imposes a tariff. However, this does not exactly mirror the real world outcome in which both of the players imposed a tariff, initiating a mini trade war. Mixed strategies Nash equilibrium was imposed in order to understand and derive the probability that a higher tariff is imposed, as both firms consider the repercussions that may arise due to this higher tariff. Even though both of the firms, before imposing the tariff, may have recognised that the equilibrium leans towards a lower tariff, they still imposed a higher tariff. As I saw in the real world outcome, both the US and the EU got approvals to impose tariffs, which caused billions of dollars worth of tariffs to be collected and a loss in revenue for either side. In theory both of the players should have refrained from imposing tariffs as it would lead to this poor result, however in real life a different situation might have played out. Firstly, it is possible that they faced quite a few political pressures from domestic stakeholders and domestic politicians, which led them to impose this tariff. For example, when the EU imposed their retaliatory tariff, valued at around $4 billion, there were some political motives behind this; industries sensitive to the Republican parties were targeted (Stearns, 2020). Furthermore, it is possible that they got caught up in the tit-for-tat trade war, and they only considered the short term output of this tariff, which was to protect domestic industries. Long-term impacts such as the market health and profit margins may not have been considered, leading to this outcome. Thus, our result may have deviated from the actual outcome, however going forward policy makers and officials must focus on the long run industry health. This is key to reduce the amount of damage caused to either industry and ensure the industry health is upheld.

Furthermore, officials at the WTO must ensure that they evaluate the long run repercussions alongside the short run impacts of granting permissions for tariffs or other trade strategies.

Moving further, using the data that I obtained from official Airbus and Boeing sources, I was able to determine the optimum output for both Airbus and Boeing. Whilst understanding the leader-follower dynamic between the two players, I derived the optimum output as 250 units for Boeing and 175 units for Airbus. This result displays a clear first mover's advantage for Boeing as they are able to produce a higher output and generate higher potential for market share capture. To ensure profitability Airbus had to limit their output to 175 units, however this compromise means that they are disadvantaged in the LCA market and they have lesser possible market share to capture. This outcome that I calculated emphasises the importance of timing and sequence of decision making, such that the firm is able to put themselves in a position to maximise market share. The ability of Boeing to produce a higher output despite the anticipated tariff imposition by Airbus suggests that Boeing has a better ability to absorb the additional costs of tariffs. This can be accredited to the large quantity of financial capital and research grants that Boeing is backed by, which allows them to sustain a higher scale of production despite the costs of tariffs. Or it may also have been the result of a long term vision, in which they were willing to incur higher costs in the short term but continue to produce more, in order to maintain their competitive edge in the long term. This result is key for policy makers, as it displayed resilience despite the tariffs. This may imply that the European government could have further escalated the situation and retaliated with another round of tariffs, so that Boeing would have to curb its production. It may also have led to a change in the rationale of European policy makers. They may have realised the lack of impact that the tariff created on the production levels of Boeing, thus they may have reevaluated the situation and considered other methods of negotiation, such as peaceful conflict resolution and forming a new agreement.

Lastly, is our model of credible threats. In this model I used backwards induction to reveal the mutual recognition of the high costs of escalating this dispute. Both of the players realise the negative playoff that arises with complaining to the WTO. The main aim of this credible threat was to push the EU to reconsider their stance on subsidisation. The US anticipated that the EU would choose not to file a counter complaint as they predicted the -10 payoff that they would face due to this, however this does not reflect the real world outcome. As we know, the EU followed the US, as they too filed a complaint to the WTO about the US's illegal subsidisation. This scenario may have arisen due to a few factors. Firstly, Airbus was determined to maintain their competitive edge and continue on their journey in which they were slowly becoming the market leaders in the LCA industry. So, they refused to stay quiet and rose to defend themselves. Furthermore, by filing this counter complaint it would strengthen their argument when they had to legally dispute with Boeing at the WTO. Lastly, as observed with the tariffs both of the players were always ready to display reciprocity and retaliation, so this may have been an effort to ensure that Boeing and the US faced the same predicament that the EU faced.

Although some of our results deviate from the real world scenario, they leave plenty of scope for the analysis of any future trade disputes. I was able to determine the reasoning behind the different measures that each of the players took, despite some of these actions reducing the payoff and reducing the overall profitability of the firm. With this I also provided context and basis for the deviations from the theoretical results that I derived.

VI. Limitations

Despite the well-rounded nature of the models that I have setup, there are a few limitations that I must consider at the end of this study.

Firstly, our models involve simplification to some degree. The real world may involve many other factors and complexities at play, which are difficult to simultaneously incorporate into these models. This may include non-financial methods of competition such as branding and market positioning, regulatory costs faced by either-firms and excessive political pressures. Secondly, in this mathematical model that revolves heavily around logical rationale. This may not match with the real world outcomes as the real life situation may not have had perfect rationality and possibly may have had an emotional component.

Moreover, the data that I had collected for our models has also gone under some simplification and estimation to make it fit into our model more accurately. This may have marginally affected our results, however not to an extent that it marks the models as inaccurate. Lastly, it is often difficult to incorporate the dynamic nature of this trade dispute in which many different conflicts and strategies take place simultaneously. It would make our models quite complex and unmanageable, thus these dynamics were excluded.

VII. Conclusion

The Airbus-Boeing trade dispute is an intricate dispute that provided us a myriad of different facets to investigate and it gave us an in depth insight into how a trade dispute functions, from start to finish. Through the use of nuanced game theory tools, such as Nash equilibrium, mixed strategies, Stackelberg competition, and credible threats I was able to model the different possible outcomes that could have arisen and compared this with the real world outcomes. Our models were able to reveal the underlying dynamics and rationales behind each of the strategies that Airbus and Boeing or the EU and the US took in order to gain a competitive edge in this market. A clearer understanding was formulated of how economic policies and other legislations can be crafted around these types of trade disputes, such that the long-run repercussions of such trade disputes can be avoided and governments can maximise the social surplus.

Our findings demonstrated that strategic interactions in such disputes are complex and multifaceted, and the game theory tools provided a clear framework to understand them. For example, the Nash equilibrium highlighted how each party's strategies escalated tensions, while the Stackelberg model emphasised the leadership dynamics that shaped the market. These insights contribute to a better understanding of the broader implications of trade disputes and the importance of carefully crafted policies.

However, there is still scope for this study going forward. In an effort to incorporate the dynamic nature of this game, an evolutionary game could be designed with an additional stochastic element to model the randomness of this game. Furthermore, further studies could also try to analyse the behavioural component, without the bounds of perfect rationality and non-emotional confinement. Emotional and irrational decision making has the power to significantly impact the way that the players choose a certain trade strategy. Lastly, this paper is able to open up the discussion of the different policies that can be designed around trade disputes. These policies include: the policies implemented to avoid and mitigate such trade disputes or policies that can be used to resolve such a dispute without the grave consequences that were observed.

To conclude, this research is able to elicit a deeper understanding of trade disputes and how economies can work through these complex disputes and foster a more stable economic environment.

References

Boeing.com (2015) 'Boeing reports first-quarter results'. Available at: **https://investors.boeing.com/investors/news/press-release-details/2022/Boeing-Reports-First-Quarter-Results/default.aspx.**

Carbaugh, R.J. and Olienyk, J. (2004) 'Boeing-Airbus subsidy dispute: A sequel', *Global Economy Journal*, 4(2), p. 1850024. doi: 10.2202/1524-5861.1047.

Chanda, S. (2011) 'The battle of the big boys: A critical analysis of the Boeing Airbus dispute before the WTO'. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1944588.

Council on Foreign Relations (n.d.) 'U.S.-Saudi Arabia relations'. Available at: https://www.cfr.org/backgrounder/us-saudi-arabia-relations#chapter-title-0-2.

European Union (2004) 'EU-US agreement on large civil aircraft 1992: Key facts and figures'. Available at: https://www.airbus.com/sites/g/files/jlcbta136/files/2021-10/EU-US-Agreement-on-Large-Civil-Aircraft-1992_1.pdf.

European Commission (n.d.) 'Press corner'. Available at: https://ec.europa.eu/commission/presscorner/detail/en/fs_21_3002.

Hossain, M.U. (2023) 'Is it Airbus vs. Boeing or EU vs. USA?: A tale of illegal subsidy'. Available at: https://doi.org/10.2139/ssrn.4817811.

Khurana, C. (2022) 'Review of game theory applications in international trade', *International Journal of English Literature and Social Sciences*, 7(1), pp. 196-206. doi: 10.22161/ijels.71.26.

Leggett, T. (2021) 'Boeing-Airbus trade row set to end after 17 years', *BBC News*, 15 June. Available at: https://www.bbc.com/news/business-57484209.

Liu, T. and Woo, W.T. (2018) 'Understanding the U.S.-China trade war', *China Economic Journal*, 11(3), pp. 319-340. doi: 10.1080/17538963.2018.1516256.

Oestergaard, K. (2024) 'Airbus and Boeing report December and full-year 2023 commercial aircraft orders and deliveries', *Flight Plan*, 15 January. Available at: https://flightplan.forecastinternational.com/2024/01/15/airbus-and-boeing-report-december-and-full-year-2023-commercial-aircraft-orders-and-deliveries/.

Roy, I., Jain, Y., Agarwal, M., Kripalani, J., Sarwate, T., and Chakraborty, O. (2020) 'Applying game theory to international relations: The case of US-Saudi Arabia crude oil price war & US-China trade war', *International Journal of Social Science and Economic Research*, 5(11), pp. 3513-3577. doi: 10.46609/ijsser.2020.v05i11.015.

SkyTough (n.d.) 'How much does a commercial plane cost?' Available at: https://www.skytough.com/post/how-much-does-a-commercial-plane-cost#:~:text=Commercial%20planes%20cost%20tens%20of%20millions%20to%20hundreds.

Sprague, K. (2019) 'Why the Airbus-Boeing duopoly dominates 99% of the large plane market', *CNBC*, 25 January. Available at: https://www.cnbc.com/2019/01/25/why-the-airbus-boeing-companies-dominate-99percent-of-the-large-plane-market.html.

Stearns (2020) 'EU gives green light to trigger $4 billion tariff strike on U.S.', *Bloomberg.com*, 9 November. Available at: https://www.bloomberg.com/news/articles/2020-11-09/eu-gives-green-light-to-trigger-4-billion-tariff-strike-on-u-s.

ScienceDirect (n.d.) 'Nash equilibrium - an overview'. Available at: https://www.sciencedirect.com/topics/computer-science/nash-equilibrium.