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NANJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS

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Flying with foresights: an interactive perspective of decision making in aviation studies

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TABLE of CONTENTS

01

Motivation

02

Graph Model for Conflict Resolution

03

Air Carbon Negotiation under CORSIA

04

Decision-making considering Geopolitical factors

05

Outlook of Research



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01

Motivation





New challenges in aviation industry

International negotiation among sovereign states: various patterns of behavior for decision makers (DMs)

Air carbon negotiation under CORSIA

		PILOT PHASE			FIRST PHASE			SECOND PHASE									
2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	
MONITORING, REPORTING & VERIFICATION TO SET THE BASELINE		VOLUNTARY <i>States are volunteering to be part of the scheme from 2021 (more States are encouraged to volunteer).</i>						MANDATORY <i>With exemptions for: Small Islands, Least Developed Countries, Land-locked Developing Countries and States which have less than 0.5% of air traffic (although they can still volunteer).</i>									
		Operators flying routes between volunteering States will offset emissions based on the average CO ₂ growth of the aviation sector.						Operators will offset based on average CO ₂ growth of the sector.			Offset obligations shift to include over 20% of individual operator growth.			Offset obligations shift to be over 70% based on individual operator growth.			
		OVER 80% OF THE GROWTH IN AIR TRAFFIC CO ₂ AFTER 2020 WILL BE OFFSET															



Various Patterns of Behavior



Zhang Fei

Aggressive



Sima Yi

Conservative

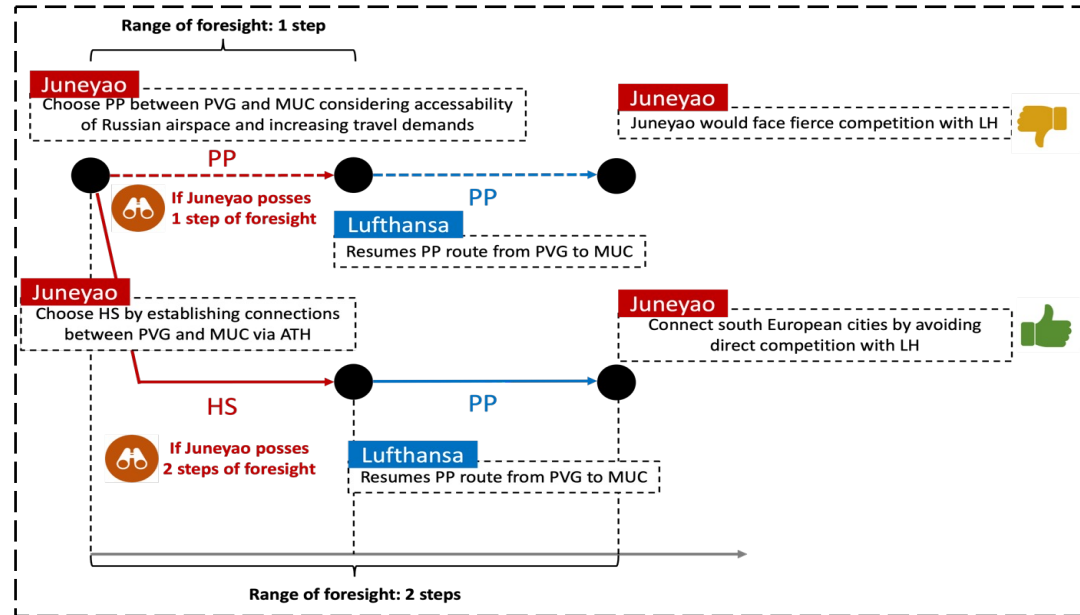
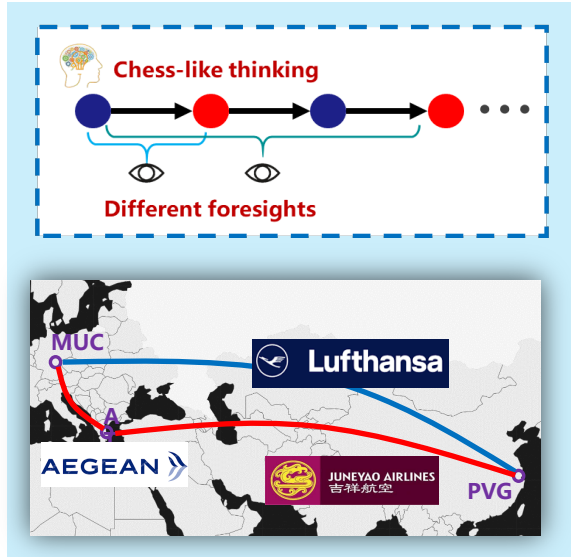


Behavior styles



New challenges in aviation industry

Network competition among airlines: tit for tat among decision makers (DMs) in multiple steps of foresight



Junyao airlines avoid direct competition with Lufthansa with mutiple foresights



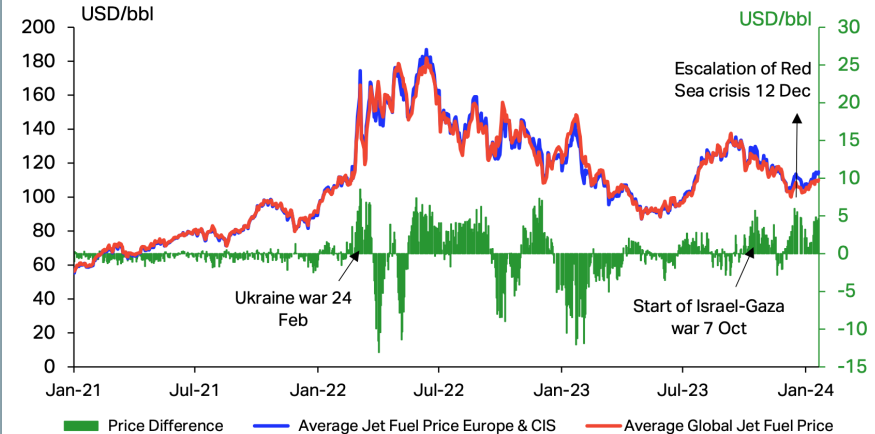
New challenges in aviation industry

Geo-politic factors in decision making: calibrate payoffs (preferences) of DMs
by considering various factors



Geopolitical tensions disrupt airline competitive landscape

Impact of Israel-Gaza War and Red Sea Shipping Disruption on Jet Fuel Prices



Source: IATA Sustainability and Economics, S&P Global Commodity Insights



Need for novel approaches

- **Emerging challenges in aviation studies:** 1) various behavior patterns, 2) multiple foresights, 3) calibration of payoffs for DMs
- **Interactive decision tools, such as game theoretic models,** have been employed to investigate international negotiations (Forgo, 2005; Madani, 2010)
- **Graph Model for Conflict Resolution (GMCR)** has been utilized for its flexible modelling approach and the capability of providing equilibria under various solution concepts (Hipel et al., 2020; He, 2022)



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02

Graph Model for Conflict Resolution (GMCR)

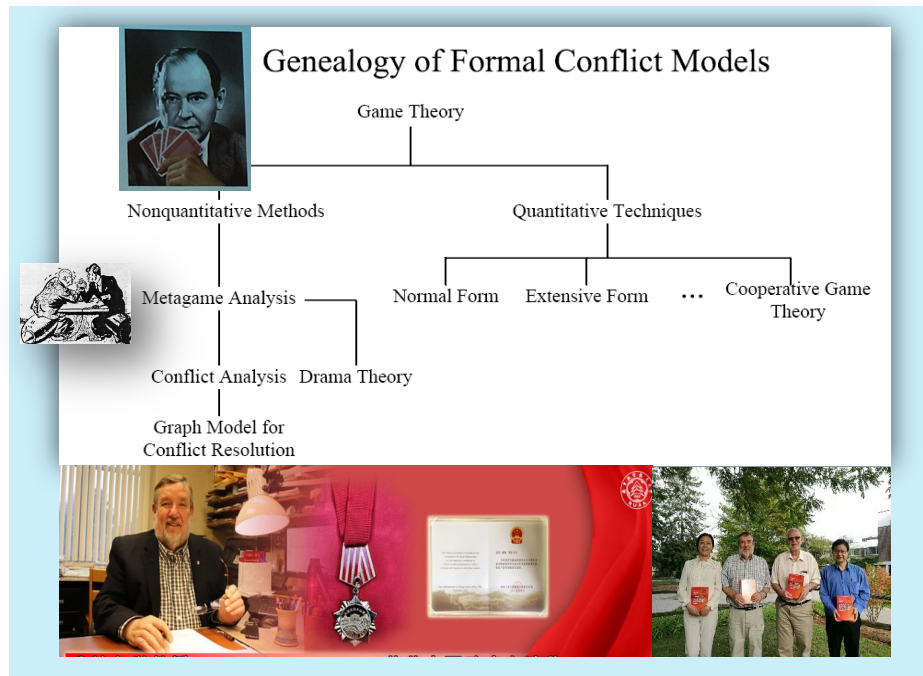




Flexible interactive decision-making tool

	GMCR	Game Theory
Value Systems	Ordinal (Pairwise comparison)	Cardinal (numbers or functions)
Order of Move	Insensitive to equilibrium	Sensitive
Equilibrium	Foresight of multiple steps (Nash, GMR, SEQ, SMR)	One-step foresight (Nash)

Comparison between GMCR and Game Theory





Modelling and Calculation

Modelling

Step 1: Identify **DMs** and their discrete **options**

Step 2: List feasible **states** represented by combination of option selection

Step 3: Elicit **preferences** for respective DMs

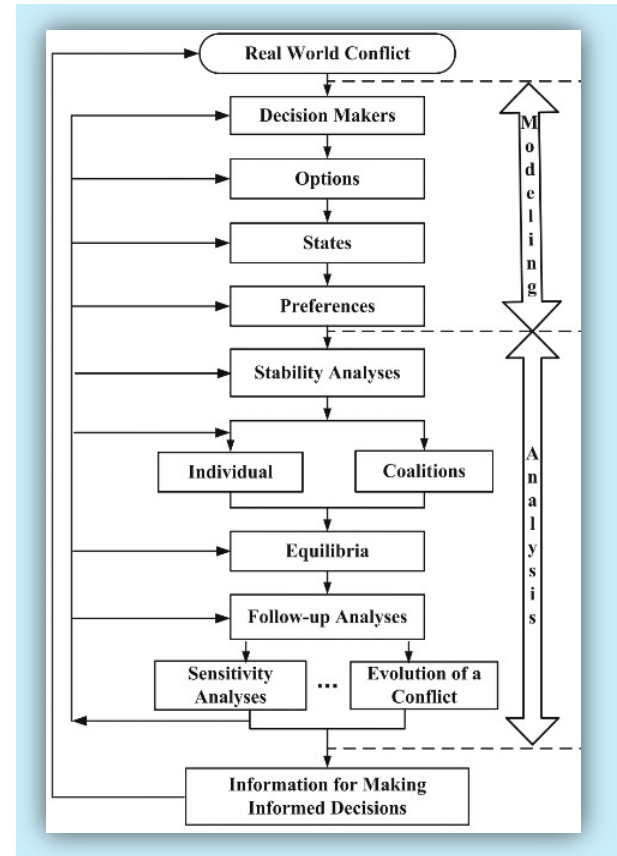
Calculation

Step 4: Calculate **individual stabilities** reflecting various solution concepts

Step 5: Calculate **equilibria** based on stabilities

Step 6: **Sensitivity** and **evolution** analysis

Step 7: Extract **managerial implications** based on equilibria





Definition of Graph Model

A graph model for conflict resolution, denoted by G , can be defined as a 4-tuple set $G = \langle N, S, A, \succsim \rangle$

N : Set of Decision Makers

S : Set of States (possible outcomes)

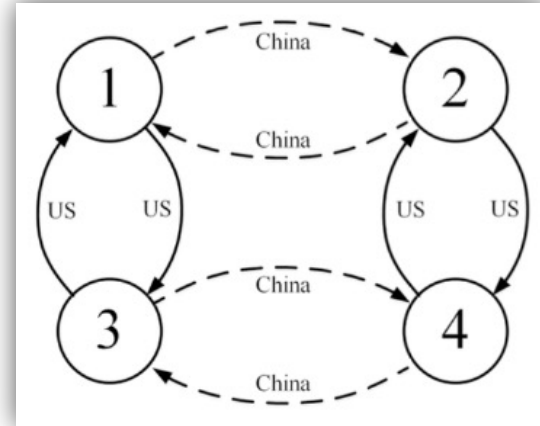
A : Arc of moves as transition of states

$\succsim$: Preference relations

Unilateral Moves (UMs)

Suppose $s, s' \in S$, the set of UMs from state s is defined as

$$R_i(s) = \{s' \in S: (s, s') \in A_i, i \in N\}$$

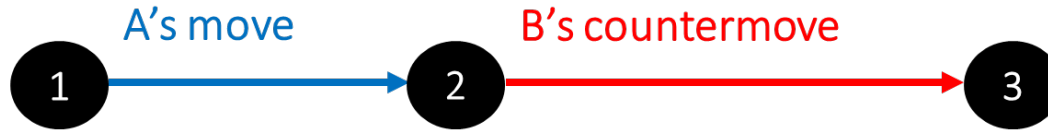


$$N = \{China, US\}$$

$$S = \{1, 2, 3, 4\}$$

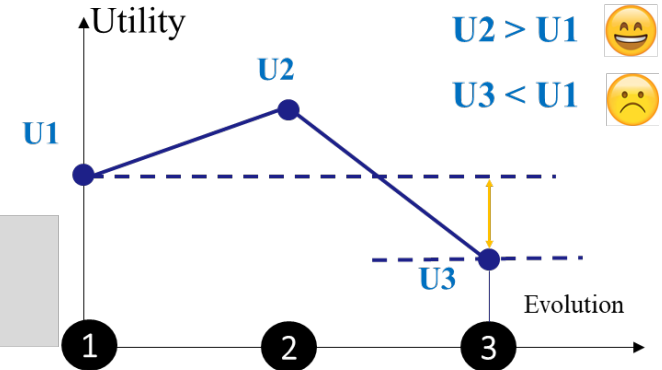
Modelling multiple foresights

Worse situations may emerge after countermoves implemented from opponent DMs



One-step foresight: A should move from 1 to 2 (Nash)

Two-step foresight: B should not move





Preference structure of GMCR

Game theory: Use cardinal numbers to represent preferences (utilities)

GMCR: Ordinal ranking of possible outcomes (relative preferences)

Pairwise comparison of states



>



Option 1	$\begin{pmatrix} N \\ N \\ Y \end{pmatrix}$	$\begin{pmatrix} N \\ Y \\ N \end{pmatrix}$	$\begin{pmatrix} N \\ Y \\ Y \end{pmatrix}$	$\begin{pmatrix} Y \\ Y \\ Y \end{pmatrix}$
Option 2	$\begin{pmatrix} N \\ N \\ Y \end{pmatrix}$	$\begin{pmatrix} Y \\ Y \\ N \end{pmatrix}$	$\begin{pmatrix} Y \\ Y \\ Y \end{pmatrix}$	$\begin{pmatrix} Y \\ Y \\ Y \end{pmatrix}$
Option 3	$\begin{pmatrix} Y \\ N \\ Y \end{pmatrix}$	$\begin{pmatrix} N \\ N \\ Y \end{pmatrix}$	$\begin{pmatrix} Y \\ Y \\ Y \end{pmatrix}$	$\begin{pmatrix} Y \\ Y \\ Y \end{pmatrix}$
	$s_1 > s_2 > s_3 > s_4$			

Utility(air) > Utility(rail)
Cardinal Preferences



Ranking of outcome (air) > Ranking of outcome (rail)
Ordinal Preferences

Less information is required in modelling payoffs of decision makers

Preference modelling in GMCR

Option Prioritization in GMCR: Ordinal ranking of options for simplifying computation (Fang et al., 2003a; b)

Ranking options instead of states: $|\text{states}| = 2^{|\text{options}|}$

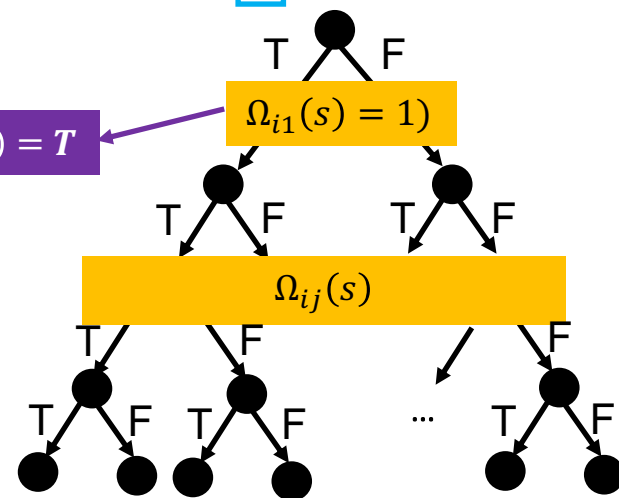
Preferences of individual DM i : a list of preference statements from the most important on top to the least at bottom $\{\Omega_{i1}, \dots, \Omega_{ij}, \dots, \Omega_{ih}\}$

Score of single statement Ω_{ij} for individual state s : $\Psi_{ij}(s) = \begin{cases} 2^{h-j} & \Omega_{ij}(s) = T \\ 0 & \text{otherwise} \end{cases}$

Score of individual state s by considering all statements: $\Psi_{ij}(s) = \sum_j \Psi_{ij}(s)$

$$\begin{pmatrix} \Omega_{i1} \\ \vdots \\ \Omega_{ij} \\ \vdots \\ \Omega_{ih} \end{pmatrix} \quad \begin{array}{c} \text{most important} \\ \downarrow \\ \text{least important} \end{array}$$

$s = (YNYN \dots N)$
option 1) 2) 3)





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03

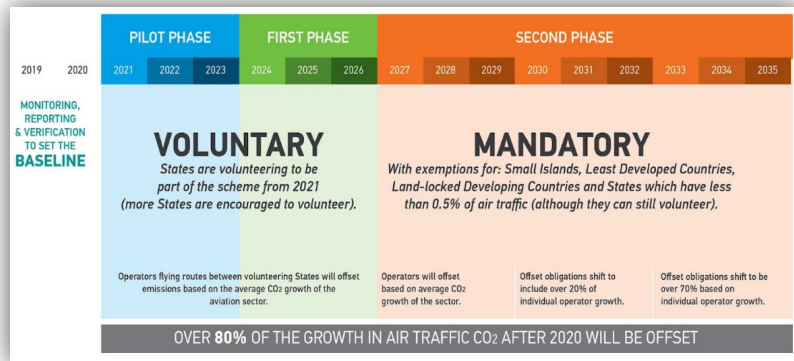
Air Carbon Negotiation under CORSIA



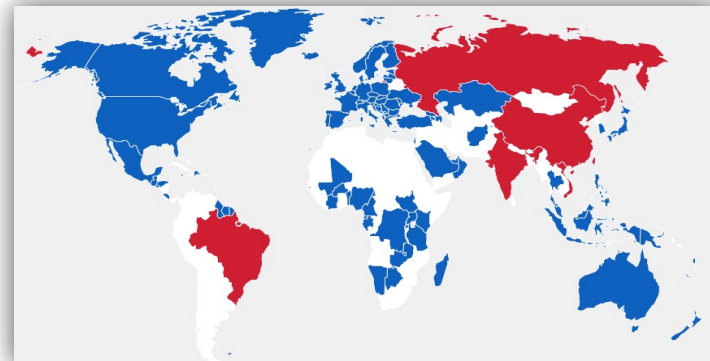


Background

- Whether to participate in CORSIA for large developing countries and when?
- What is an agreed baseline by defining the “**shared but differentiated responsibility**”
- How to be compatible with domestic carbon schemes (e.g. EU-ETS)



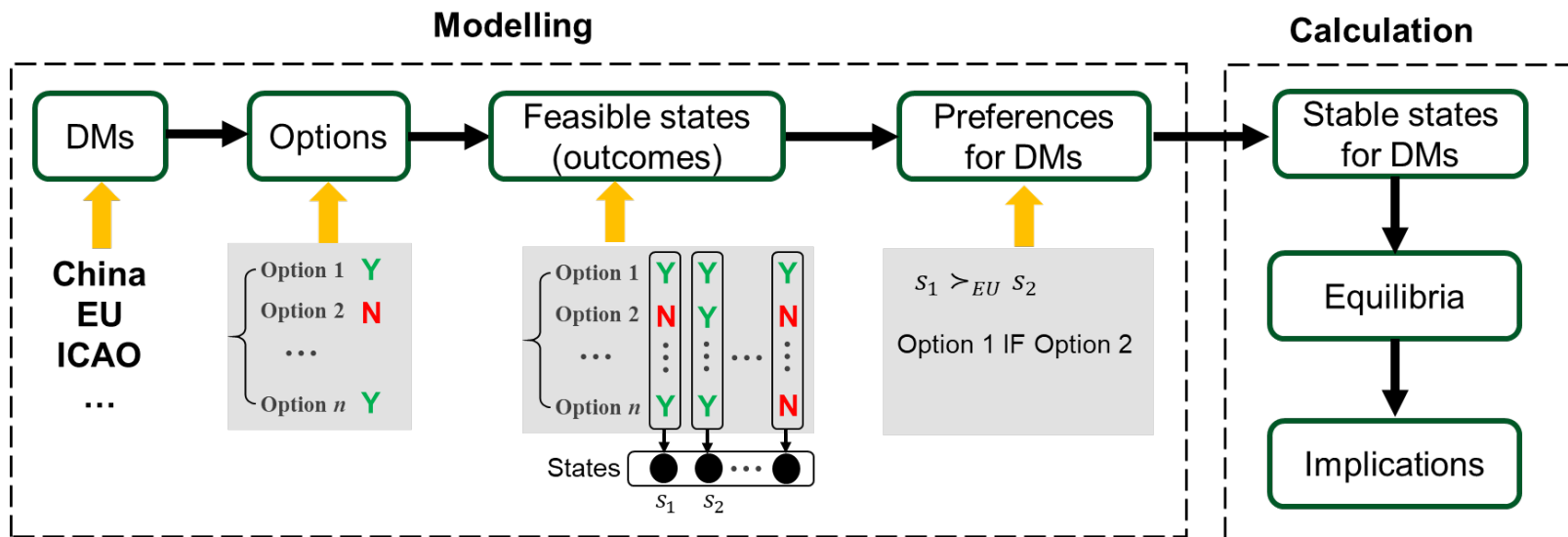
Phases of CORSIA



Countries in CORSIA (in blue) and non-participating countries (in red)



Modelling steps



Developed
methodologies

- **Hierarchical structures** (He et al., 2013; 2017; 2021)
- **Time sensitive moves** (He, 2022)
- Preference modelling considering **responsibilities**

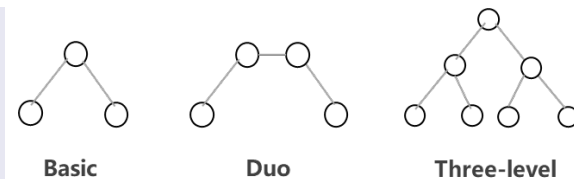


Hierarchical structure of negotiation

Hierarchical graph models can handle negotiation at multiple levels

• Types of Hierarchical Graph Models

Basic (He et al., 2013), Duo (He et al., 2017a), Three-level (He et al., 2021), General (He et al., 2017b)



• Different order of choosing options in subconflicts

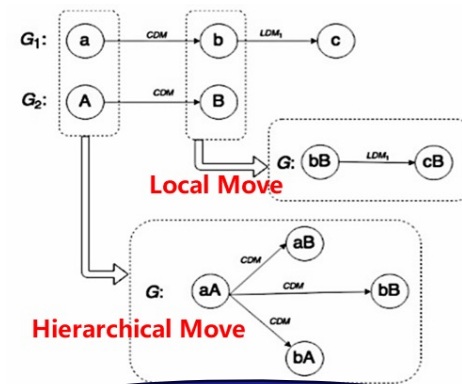
Hierarchical States: Cartesian Product of sets of states in local models:

$$S = S^{(1)} \times S^{(2)}$$

Hierarchical Moves: Cartesian Product of sets of moves in local models

(1) Common Decision Maker (CDM): $AC = AC^{(1)} \times AC^{(2)}$

(2) Local Decision Maker (LDM): can only move within its local model



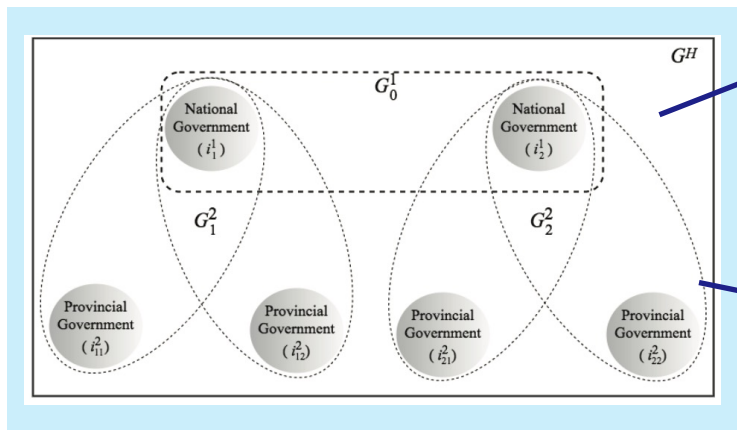
May decide which local
move more important



Climate negotiation between two states

Horizontal: bilateral negotiation over signing climate treaty at national level

Vertical: coordinating interests with provincial governments within nations



National Level

DMs	Options	States			
National Govt i^1_1	o_1 : Sign	N	Y	N	Y
National Govt i^1_2	o_2 : Sign	N	N	Y	Y
		(NN)	(YN)	(NY)	(YY)

Provincial Level

DMs	Options	States			
G^1_{11}					
i^1_1	o_3 : Existing Laws/Stricter Laws	N	Y	N	Y
i^2_{11}	o_5 : Agree/Disagree	N	N	Y	Y
G^1_{12}					
i^1_1	o_3 : Existing Laws/Stricter Laws	N	Y	N	Y
i^2_{12}	o_6 : Agree/Disagree	N	N	Y	Y
G^1_{21}					
i^1_2	o_4 : Existing Laws/Stricter Laws	N	Y	N	Y
i^2_{21}	o_7 : Agree/Disagree	N	N	Y	Y
G^1_{22}					
i^1_2	o_4 : Existing Laws/Stricter Laws	N	Y	N	Y
i^2_{22}	o_8 : Agree/Disagree	N	N	Y	Y



What can hierarchical equilibria suggest?

Policy implications from calculated equilibria

- Whether **respective options** ought to be selected (package of policies)
- Whether the **importance** assigned to **subconflicts** is appropriate
- Impact** of preference patterns and importance of subconflicts on hierarchical equilibria

	G_0^1 $o_1 o_2$	G_1^2 $o_3 o_5 o_6$	G_2^2 $o_4 o_7 o_8$	G^H $o_1 o_2 o_3 o_4 o_5 o_6 o_7 o_8$
i_1^1	(N Y) (N N)	(N - Y) (N - N) (Y - Y) ^s		(N Y N - - Y - -) (N Y N - - N - -) (N N N - - Y - -) (N N N - - N - -) (N Y Y - - Y - -) ^s (N N Y - - Y - -) ^s
i_{11}^2		(Y Y -) (N N -) (Y N -) ^s		(- - Y - Y - - -) (- - N - N - - -) (- - Y - N - - -) ^s
i_{12}^2		(Y - N) (N - N) (Y - Y)		(- - Y - - N - -) (- - N - - N - -) (- - Y - - Y - -)
i_2^1	(Y Y) (N Y)		(Y Y -) (N N -)	(Y Y - Y - - Y -) (Y Y - N - - N -) (N Y - Y - - Y -) (N Y - N - - N -)
i_{21}^2			(Y Y -) (N N -)	(- - - Y - - Y -) (- - - N - - N -) (Y N - Y - - N -) (N N - Y - - N -)
i_{22}^2			(Y - Y) (N - N) (Y - N) ^s	(- - - Y - - - Y) (- - - N - - - N) (- - - Y - - - N) ^s
Equilibria	(N Y)	(Y - Y) (N N N)	(Y Y -)	(N Y N N N N N N) (N Y N Y N N Y -) (N Y Y Y - Y Y -) (N Y Y N - Y N N)



Time sensitive approach



- Time window of participation
- Voluntary before 2027
- Deadline in each phase

Time sensitive features

- Uneven time of taking actions (moves)
- Moves taking less time will be initiated
- Constrained by periodical deadlines

Time sensitive graph model

Time frame: 2019 - 2020

DMs and Options

EU:

- 1) **Adjusting ETS MRV** to tackle double calculation on international flight
- 2) Change CORSIA baseline

DC:

- 3) Appeal for **changing ETS MRV**
- 4) Appeal for changing CORSIA baseline

US:

- 5) Voluntary MRV by FAA
- 6) Appeal for changing ETS MRV
- 7) Appeal for changing CORSIA baseline



Preferences and time based on historical news

Preferences in option prioritization

DMs	Preference Statements	Description
EU	2) IF 4)&7)	EU will agree to change baseline when both DC and US have same request.
	1) IF 3)&6)	EU will adjust EU ETS when both DC and US have the same request.
	-1)	EU does not wish to change EU ETS.
DC	2)	EU wishes to change CORSIA baseline.
	2) & 7)	DC wishes to see the change of baseline by both EU and US.
	4)	DC will appeal for baseline change.
	1)	DC expects EU to adjust EU ETS MRV.
US	3)	DC will appeal for the change of EU ETS MRV.
	3) & 6)	DC expects US to appeal for the change of EU ETS MRV as well.
	5)	US implements voluntary monitoring policy.
	1)	US expects EU to adjust EU ETS MRV.
	6)	US will appeal for the change of EU ETS MRV.
	3)	US expects DC to appeal for the change of EU ETS MRV.
	3) & 6)	US and DC appeal at the same time.
	7)	US will appeal for the change of CORSIA baseline.
	2) 4)	Either EU or DC appeals for changing baseline

Time for completing moves

	ToMs	Duration (YYYY/MM/DD)	Descriptions or Sources
State 1	$\tau_{DC}^4(1, 3)$	2 months	India filed reservation on baseline (A)
	$\tau_{US}^7(1, 7)$	15 months	US issued voluntary monitoring policy (B)
	$\tau_{US}^6(1, 13)$	>18 months	US appeals for changing EU ETS MRV after June 2020 (C)
State 3	$\tau_{EU}^2(3, 4)$	16 months	EU adjusted CORSIA baseline in light of COVID (D)
	$\tau_{DC}^3(3, 9)$	14 months	(A) See sources
	$\tau_{US}^6(3, 16)$	>17 months	(C) See sources
State 9	$\tau_{DC}^6(3, 31)$	16 months plus 1 day	US backed EU for baseline change (E)
	$\tau_{EU}^9(9, 10)$	4 months	(D) See sources
	$\tau_{DC}^3(9, 11)$	>4 months	(C) See sources
State 10	$\tau_{US}^6(10, 26)$	After 2020/07	(C) See sources
	$\tau_{DC}^3(10, 36)$	1 day	(E) See sources
	$\tau_{DC}^3(10, 12)$	After 2020/07	(F) DC appeals for changing EU ETS MRV after July 2020

Sources:

(A): [www.icao.int >wp_228_rev1_zh](https://www.icao.int/wp_228_rev1_zh).

(B) FAA document (2019): https://www.faa.gov/about/office/headquarters/offices/apl/research/environmental_policy/media/corsia_mrv_program_statement.pdf.

(C): <https://www.euractiv.com/wp-content/uploads/sites/1/2020/05/Letter-regarding-adjustment-of-the-CORSIA-baseline-1.pdf>.

(D): <https://www.consilium.europa.eu/en/press/press-releases/2020/06/09/aviation-emissions-eu-adopts-its-position-on-adjusted-corsia-baseline-to-take-account-of-the-consequences-of-covid-19-pandemic/>.

(E): <https://www.greenaironline.com/news.php?viewStory=2706>.

Based on historical news



Equilibrium and Evolution of Conflict

Equilibrium for respective phases

State 36 for Baseline phase

EU and US changed baseline by June 20, 2020

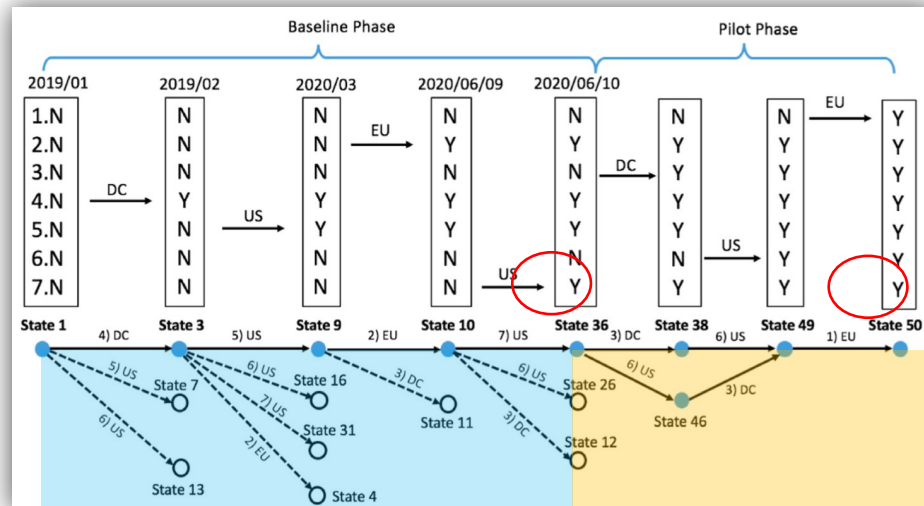
State 50 for Pilot phase

Adjustment of MRV by EU to avoid double calculation

Policy Implications

- EU was the first to announce baseline change after the outbreak of pandemic
- MRV was less urgent compared with the change of baseline
- EU revised MRV on June 2023

Evolution of CORSIA negotiation



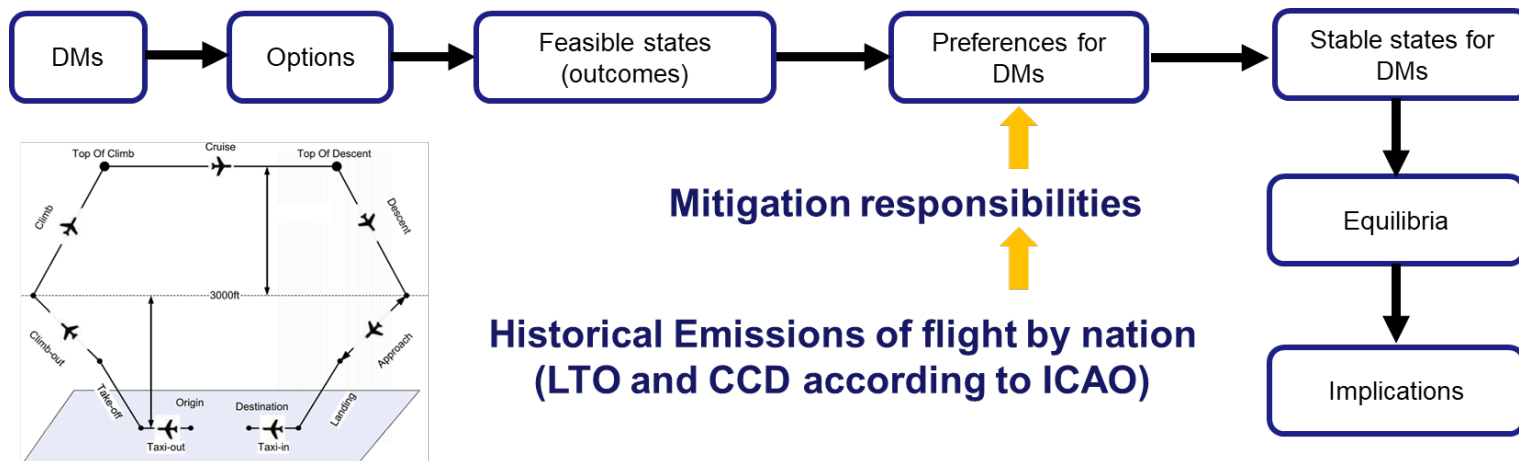
Review of historical evolution
(2019-2020)

Outlook of future
evolution (2020-2023)



Preference modelling considering responsibilities

Elicitation of Preferences for DMs by **considering uneven emission responsibilities** among participating states





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04

Decision-making considering Geopolitical factors





Topic 1: Closure of Russian airspace

Historical Evolution





Calculated evolution by scenario

Scenario 1: Simple version

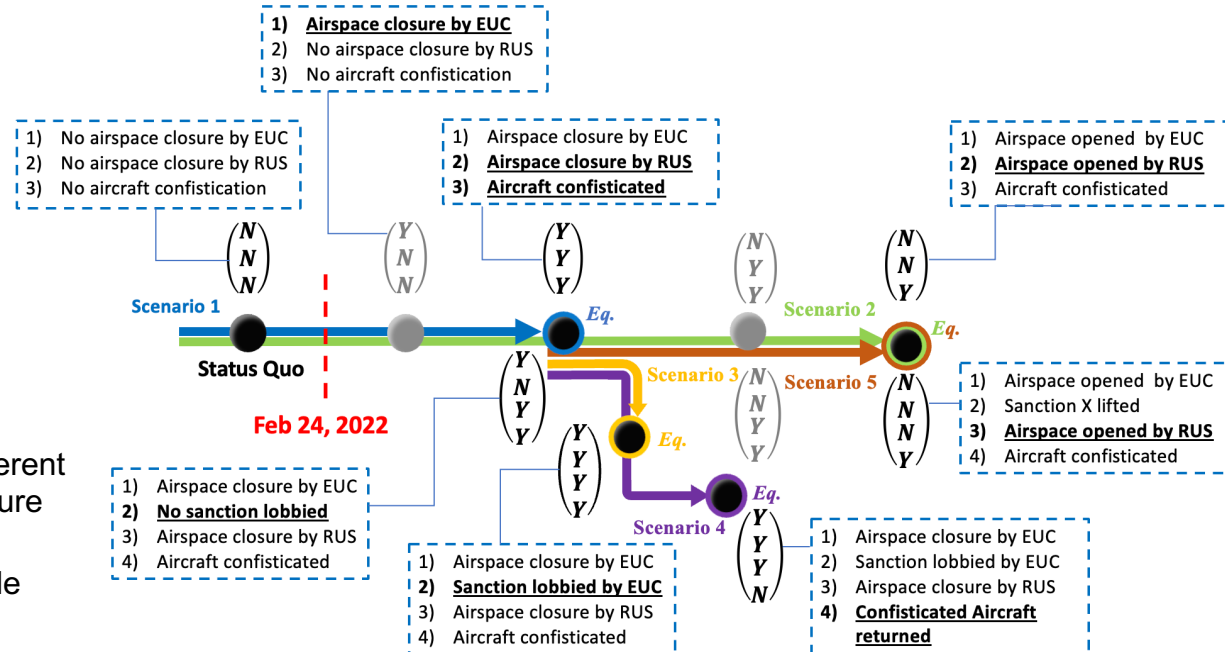
DMs	Options
EUC	1) Closure of Airspace to RUS
RUS	2) Retaliating Closure of Airspace 3) Nationalize leased aircraft

Scenario 2: EUC reopens its airspace

Scenario 3: Considering international sanctions from ICAO

Scenario 4: Imposing sanction with different strength for EUC to revert airspace closure

Scenario 5: EUC reopens airspace while considering sanctions





Topic 2: Disputes over flying routes between China and US

Regulators in US government demand Chinese airlines to avoid flying over Russian airspace for fair competition

Question: How would Chinese airlines respond and what would be an agreement?

DMs	Options	Preference statements
US Dept. Transportation	1. Increase flights	-1) & -2)
	2. Decrease flights	-2) IF 6) 1) IFF 5)
US airlines	3. Increase flights	-3) IF 2)
	4. Alternative modes of operation (code share)	4)
CAAC	5. Increase flights	5)
	6. Decrease flights	6) IF 2)





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05

Research Outlook





Conclusions

- **Interactive decision-making** tools like GMCR can handle strategic disputes in aviation industry
- Managers are suggested to make strategic decisions with **longer foresights** by considering actions from counterparts
- Reasonable decisions by considering **geopolitical factors** can be achieved using concrete tools





Further study

- Considering **coalition** (alliance) in network competition
- Attention on ongoing disputes of CORSIA in future phases
- Incorporate **data (GDELT)** and the analytical tools for analyzing interactions among sovereign states



AFCS 2025, Ho Chi Minh City, Vietnam



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THANKS

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