# AIM-OS:
# Aviation Integrated Modelling
# Open Source

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# Overview

# Aviation Integrated Modelling

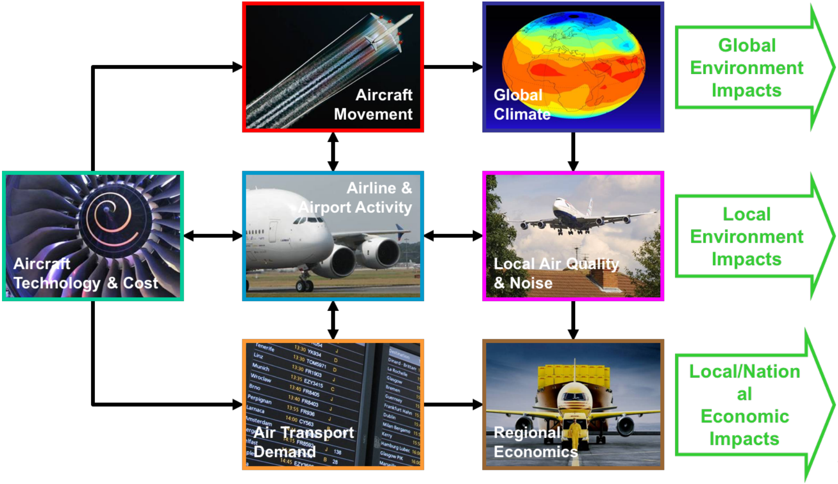
- AIM - global aviation policy assessment tool in development since 2007 and used in numerous publications.
- Allows for comprehensive analyses of aviation, environment and economic interactions, at both local and global level.
- Composed of a set of inter-linked modules modelling key elements of global aviation.
- Current work: Update for an **Open Source** release to the community $\sim$ Oct 2016.

# AIM Project History

- In development since 2007
- Involvement of large number of institutions and collaborators

- With funding from:

# AIM Architecture



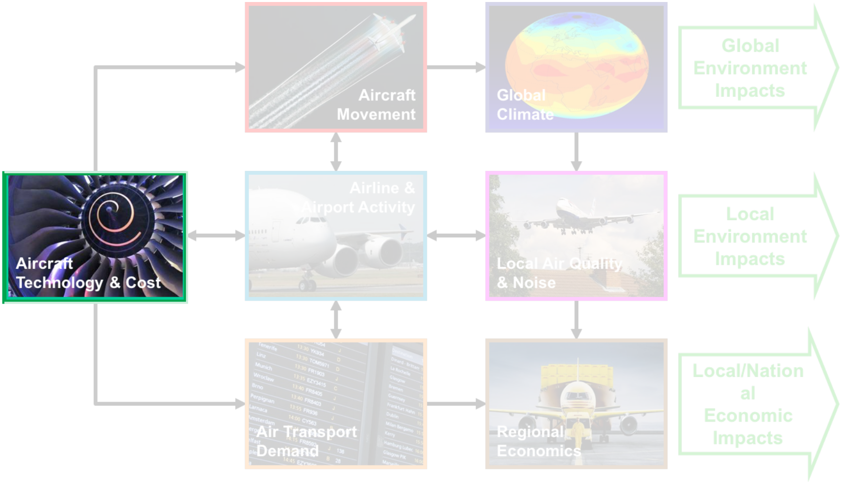

[1]

[1] Reynolds, 2007

# AIM Architecture

- Modular design has a number of benefits:
  - Temporal and spatial resolution can be tailored to the application.
  - Modules can be run independently.
  - Permits extensions and developments of the capabilities of the different modules.
  - Each module is an input site for policy levers.

# Aircraft Technology and Cost



# Aircraft Technology and Cost

- Simulates fuel burn, emissions and operating costs by stage length and load factor for airframe and engine technologies to 2050.
- Fleet aggregated into 3 categories based on size:
  - $<$ 199, 190-300 seats, $>$ 300 seats
- Fuel burn and emissions costs:
  - below 3,000ft estimated from ICAO Exhaust Emission Data, LTO cycle
  - above 3,000ft estimated using EUROCONTROL Base of Aircraft Data
- Non-fuel related operating costs estimated using US DOT form 41 airline financial data adjusted for global differences based on ICAO data.

# Future Technology

A range of advanced technologies are considered to become available:

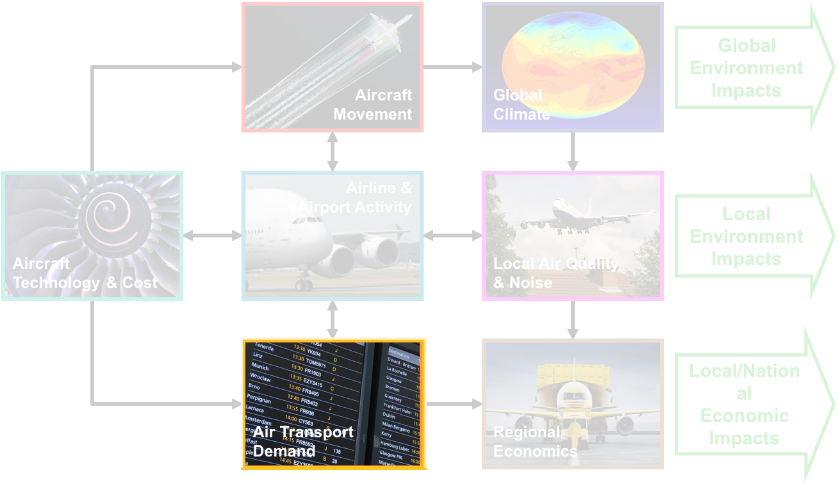
- Biofuels:
  - 20-50% blend possible by 2020
- New Aircraft technology:
  - Fuel burn of new aircraft models improves 1% per year
  - ATM improvements - 4% decrease in fuel burn globally
  - Retrofits, e.g. winglets

| Tech | Year | Reduction |
|---|---|---|
| Composite Evolutionary Replacement Narrowbody | 2025 | 22% |
| Open Rotor Narrowbody | 2025 | 35% |
| Blended Wing Body Widebody | 2037 | 30% |

# Aircraft Technology and Cost

- Airlines make decision to invest in current or future technology based on cost.
- For alterations to existing aircraft three year payback period is used.
- For new aircraft types Net Present Value model is used.
- Parameters derived from financial reports and vary by region
- Effective payback for new aircraft in US $\sim$ 7.5 years, Africa $\sim$ 6.2 years.

# Air Transport Demand



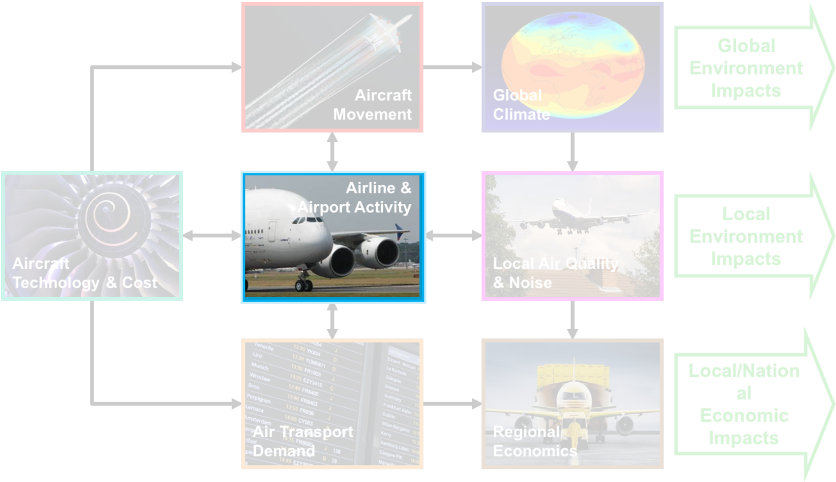
# Air Transport Demand

Simulates O-D demand for 700 cities (1127 airports) - accounting for 95% of global scheduled RPK.
Gravity Equation:

$$D_{i,j} = (P_i P_j)^{\alpha} (I_i I_j)^{\gamma} e^{\delta A_{i,j}} e^{\epsilon B_{i,j}} e^{\varphi S_{i,j}} (\overline{\text{Fare}}_{i,j} + \theta_1 \overline{T}_{i,j} + \theta_2 \overline{\text{Delay}}_{i,j})^{\tau}$$

- Population and income are assumed to grow according to forecasts from the MIT Integrated Systems Model for the US CCSP.
- Demand growth rates predicted consistent with industry projections $\sim 5\%$
- Fare and delay feedback from Airline and Airport Activity Module.

# Airline and Airport Activity



# Airline and Airport Activity

Forecasts the air traffic required to satisfy the demand projected by the demand module and resulting delay.

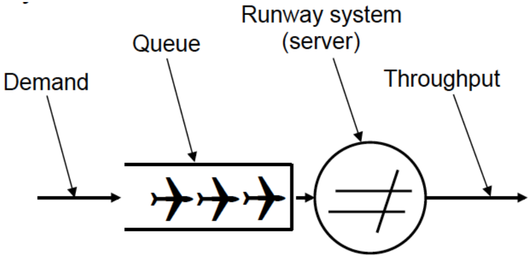
- Aircraft choice modelled by Multinomial Logit model:
  - Segment passenger demand
  - Stage length
  - Type of route (hub-spoke, etc)
- Average delay at airport predicted based on schedule and airport capactiy.
- Base year network applied to all forecasts
  - No network change modelled

# Modelling Fares

- Real world airline fare setting governed by complex revenue management in order to capture consumer surplus.
- Instead, average city-pair fares estimated assuming constant rate of return:
  - Ratio of operating cost and fares remains constant
  - Rate of return does not vary significantly across most networks
  - Tight linear relationship between observed operating cost per RPK and observed yield
  - In many market network-wide rate of return is low, suggesting these markets experience high fare competition.

# Modelling Delay

- Runways typically primary bottleneck in system
- Delays resulting from airport capacity constraints modelled using queueing theory

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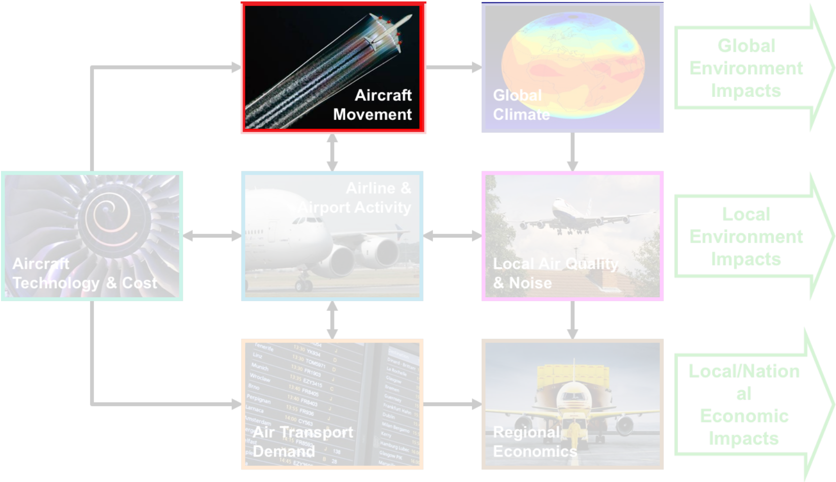
- Delays affect airline costs and passenger travel time
- Based on airport capacities (aircraft per hour)

[2] Evans 2008

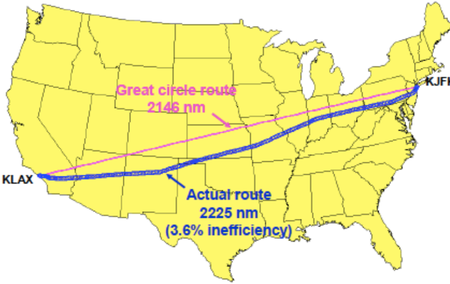
# Aircraft Movement



# Aircraft Movement

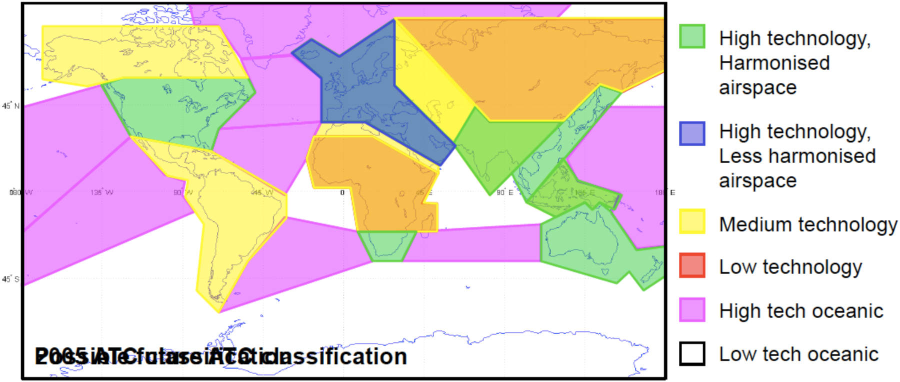
Simulates location of emissions released from aircraft in flight, accounting for ATM inefficiencies

- Calculate optimal routes between airport pairs, great circle.
- Add inefficiency factors to account for air traffic control
- Inefficiency factors vary by region and by time

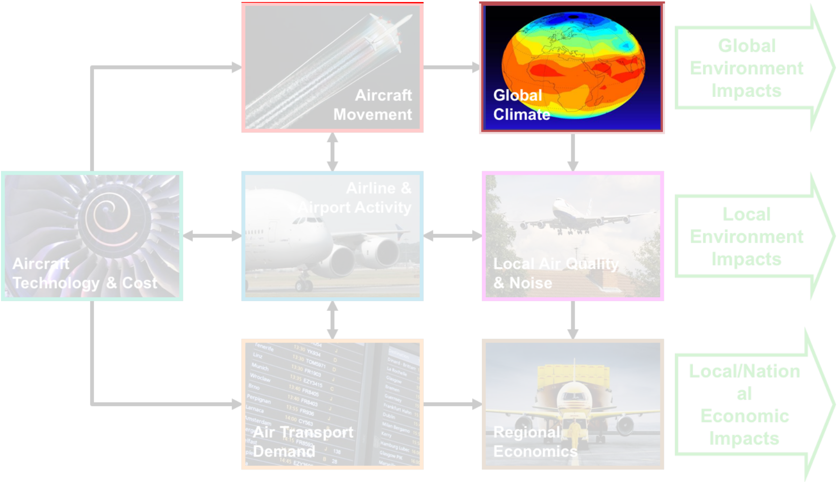


# Aircraft Movement

- Inefficiency factors defined for different world regions
- Optimal routes degraded by restrictions (military, weather), conflict avoidance (separation minima)



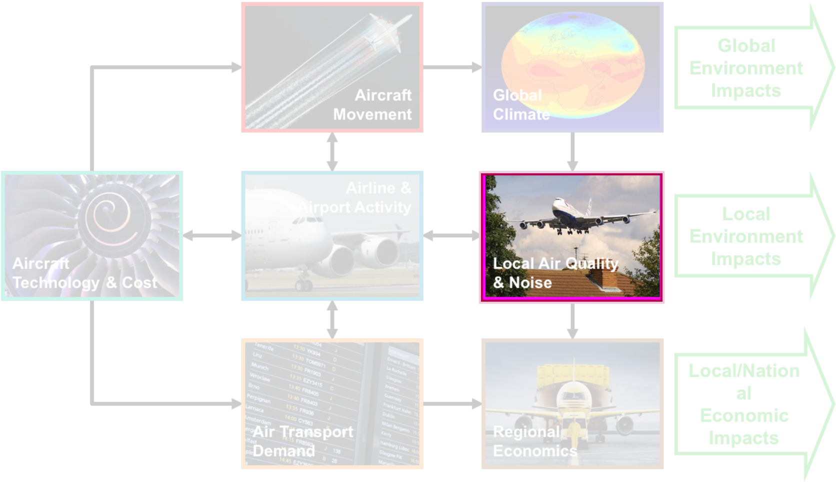
# Global Climate Module



# Global Climate Module

- Takes aircraft emissions from Airport Movement module and determines impact on global climate system.
- Three possible configurations of reducing complexity
  - Global climate model
    - Atmospheric circulation, applied chemistry transport, radiative forcing -> future meteorological conditions
  - Chemistry transport model
    - Atmospheric circulation, applied chemistry transport
    - Offline radiative forcing and external meteorological conditions
  - Simple parametric model
    - Parametric version of chemistry transport model
    - Allows large number of sensitivity studies at low computational cost

# Local Air Quality and Noise



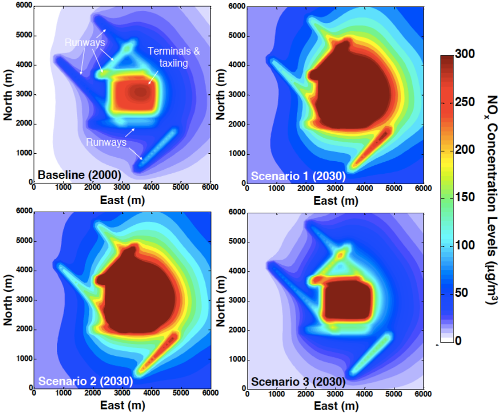
# Local Air Quality and Noise Module

Simulates dispersion of critical pollutants ($NO_x$, $O_3$, PM)

- Emission dispersion impact parameter estimated using meteorology parameterization
  - LTO time, emissions and path inputs from Airline and Airport Activity Module
- Emissions concentrations estimated using dispersion model
  - Dispersion impact parameter and source parameter (from source pre-processing) impacts
- LAQ contours estimated using atmospheric chemistry model based on emission concentrations
- Noise contours estimated using Industry Noise Model
- Outputs:
  - $NO_x$, $NO_2$, $PM_{10}$ and $PM_{2.5}$ concentrations, noise contours/population impacts

# LAQ Chicago O'Hare

- Annual local $NO_x$ emissions under 3 scenarios:

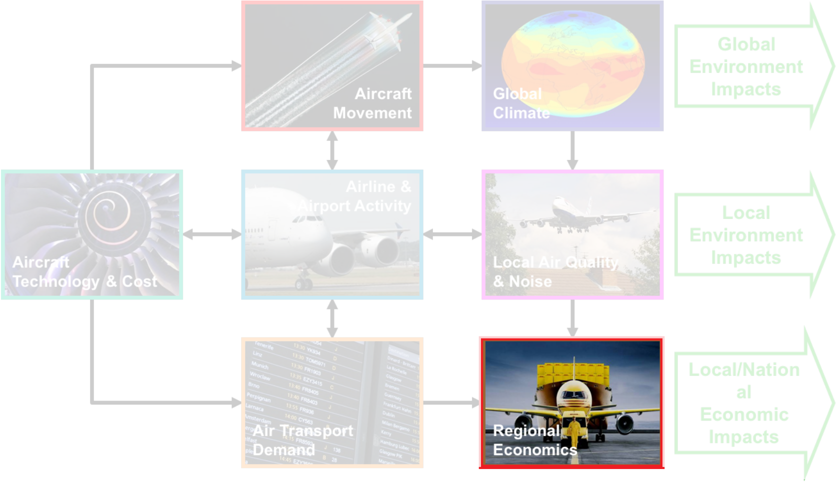



1) Unconstrained system no feedback

2) feedback of delay

3) feedback + Per-Km tax policy

# Regional Economics



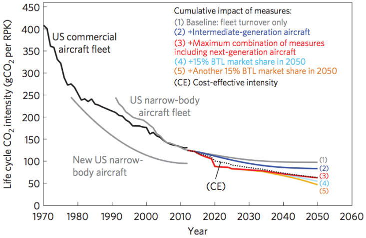
# Regional Economics Module

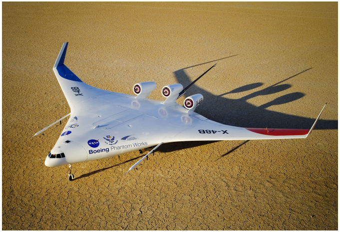
- Positive regional impacts:
  - Direct (e.g. jobs at the airport)
  - Indiret (e.g. jobs at local hotels, business relocation)
  - Induced (e.g. jobs at suppliers of local hotels)
- Negative regional impacts:
  - Local air pollution ($NO_x$, $SO_x$, $PM_{2.5}$) - health impacts
  - Noise around airports - lowers property values
  - Visual intrusion, landscape degradation
  - Climate impacts through contrails and emissions
- Conversion factors used to convert pollutant concentration or marginal effect of emissions into health effects/economic costs

# AIM in Practice

AIM can be used to:

- Simulate impacts of new technologies and changes to fleet composition on CO2, cost reduction etc.
- Test new policy measures, carbon tax.
- Assess impacts of traffic growth in light of constrained airport capacity.
- Local effects such as noise.



# Example Case Study

Integrated modelling allows us to test global aviation response to theoretical climate mitigation policies

- Replacing older aircraft with newer fleet could significantly improve emissions.
- Policy: Revenue from worldwide aviation carbon tax used:
  - to fund fleet replacement for all airlines.
  - to promote technology transfer to developing countries.

# Future Scenarios

- MIT Integrated Global Systems Model (IGSM)
  - High GDP growth, high oil price
- Model for Evaluating the Regional and Global Effects of GHG Reduction Policies (MERGE)
  - Medium GDP growth and oil price
- Joint Global Change Research Institute's Climate Assessment Model (miniCAM)
  - Low GDP growth, low oil price

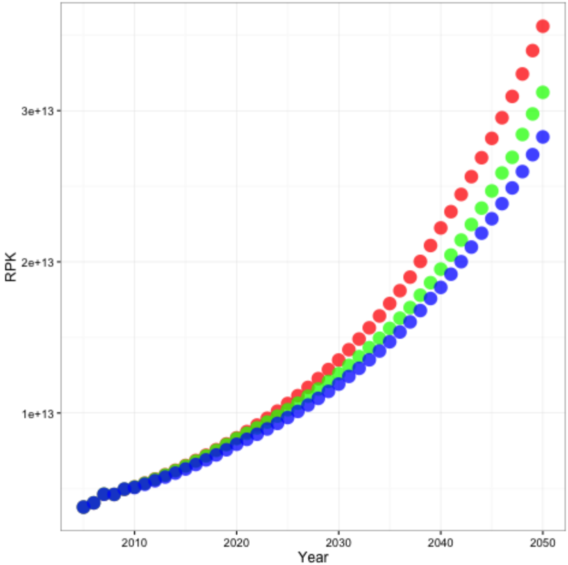
# Future Scenarios

| | Scenario | US | Western Europe | Eastern Europe - Former Soviet Union | China | India | Japan | Africa - Latin America -Rest of the world |
|---|---|---|---|---|---|---|---|---|
| Pop growth (%/year) | IGSM | 0.6 | -0.2 | -0.3 | 0.3 | 0.9 | -0.2 | 1.3 |
| | MERGE | 0.4 | 0.0 | -0.1 | 0.3 | 0.7 | 0.0 | 1.1 |
| | MiniCAM | 0.6 | 0.0 | -0.1 | 0.2 | 0.8 | -0.2 | 1.2 |
| GDP/capita (%/year) | IGSM | 2.2 | 2.9 | 4.0 | 4.0 | 2.5 | 3.1 | 1.9 |
| | MERGE | 1.4 | 1.7 | 3.4 | 4.5 | 4.3 | 1.3 | 2.5 |
| | MiniCAM | 1.3 | 1.0 | 3.3 | 5.1 | 4.8 | 1.2 | 1.9 |

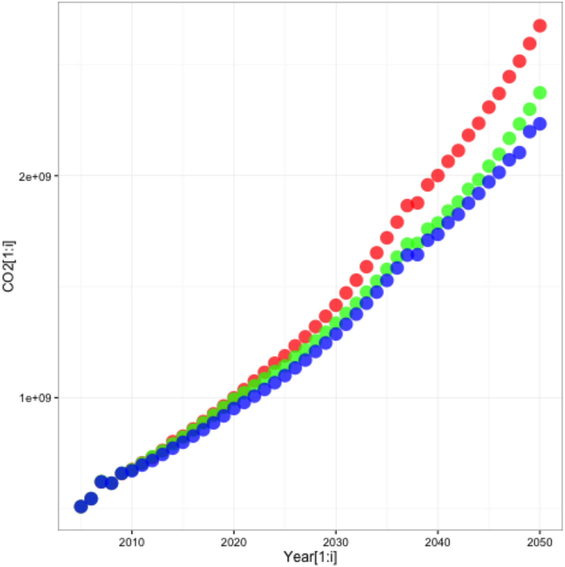
| | | 2020 | 2040 |
|---|---|---|---|
| Oil price ($2005 per barrel) | IGSM | 106.0 | 153.9 |
| | MERGE | 82.4 | 123.6 |
| | MiniCam | 73.7 | 92.2 |

- Result in demand growth rates consistent with sector wide projections:
  - IGSM 5.1%, MERGE 4.8% and MiniCAM 4.6%
- Global average $CO_2$ emissions growth of 3.8%, 3.5% and 3.1%.

# Base Scenario Growth in RPK



# Base Scenario Growth in CO2 Emissions



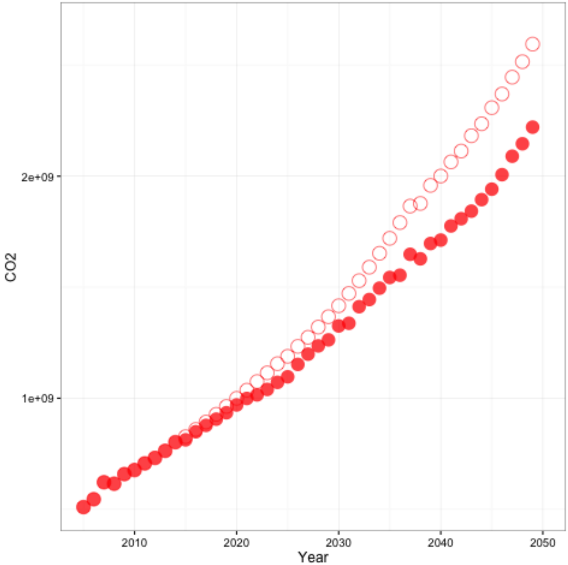
# Fleet Replacement subsidized by Carbon Tax Policy

- Replacing all current aircraft with the latest technology could produce a 10% reduction in aviation $CO_2$ (Dray 2014).
  - However, extremely unlikely that large numbers of aircraft will undergo early retirement without incentives.
- Simulate a policy to subsidize fleet renewal via carbon tax
  - Begins 2015 replacement of all aircraft over 30 years old
  - 2015-2025 threshold is tightened to retirement age of 20 years
  - Carbon tax calculated based on numbers and types of aircraft over the age threshold
  - Changes each year
- Two variations:
  - Global fleet subsidized
  - Only developing countries subsidized (global tax)

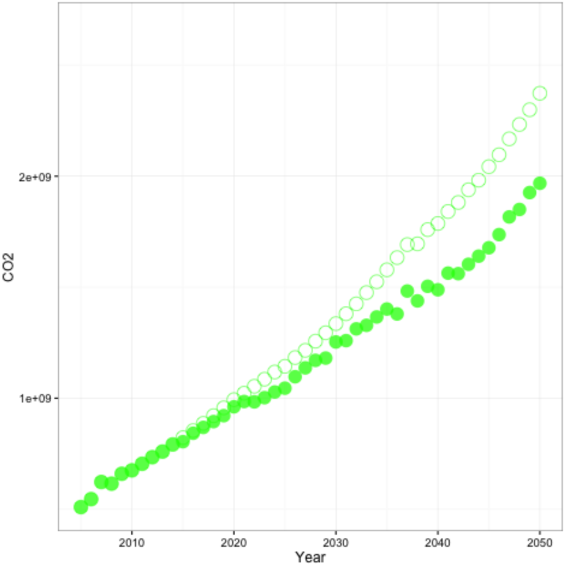
# Policy Effects

- Policy has three primary effects
  - Funds fleet renewal with advanced technology
  - Increase passenger costs and reduce demand
  - Airlines incentivised to apply cost-effective mitigation measure to reduce emissions and lower costs i.e. maintenance.

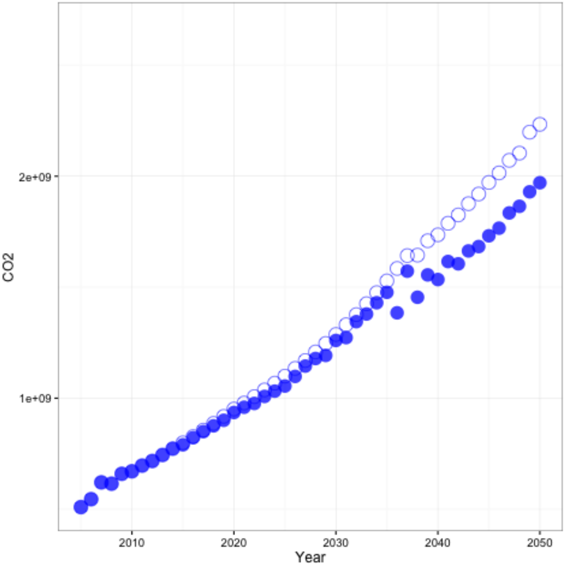
# Policy Results IGSM CO2 Emissions



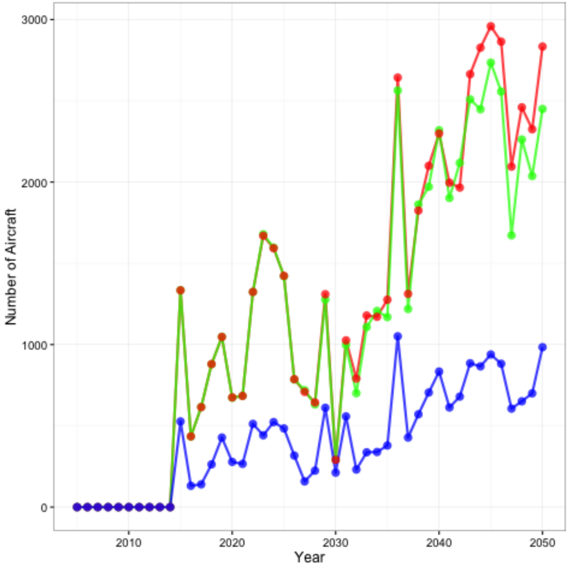
# Policy Results Merge CO2 Emissions



# Policy Results MiniCAM CO2 Emissios



# Fleet Replacement



# Global Policy Evaluation

- Compared to no-policy RPK declines 10-12% by 2050.
  - Long haul affected more,
  - flights $<$500 miles 6-7% decline
  - flights $>$500 miles 11-13% decline
- Total decrease in CO2 emissions of 29-34% by 2050.
  - $\sim \frac{1}{3}$ comes from reduction in demand
  - $\sim \frac{1}{3}$ new technology
  - $\sim \frac{1}{3}$ increased adoption of biofuels

# Regional Policy Evaluation

- Regional policy leads to reduction in $CO_2$ emissions of $\sim 25\%$
- Less effective than global policy
- Costs are much lower
  - Global policy cost of reducing lifecycle $CO_2$ by 1 tonne \$40-80 /t$CO_2$
  - Regional policy cost of reducing lifecycle $CO_2$ by 1 tonne \$20-50 /t$CO_2$

# Future Developments

- Update base year of AIM from 2005 to 2015.
- Release open source version, $\sim$ Oct 2016.
- ACCLAIM, Airport Constraint Consequences Leveraging AIM
  - Combines AIM with Airline Response Model (ARM).
  - ARM: simulates competitive game between airlines to maximise profit.
  - Develop a fare model estimating average airline itinerary fares.
  - More advanced passenger choice model.
- Conduct simulation studies to assess the impact of future constrained airport capacity on aviation network.
  - Example Heathrow/Gatwick additional runway.

# Team

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# References

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- *Costs of Mitigating $CO_2$ Emissions from Passenger Aircraft.* Schafer et al. 2015
- *Airline Fleet Replacement Funded by a Carbon Tax: An Integrated Assessment.* Dray et al. 2014.
- *Rapid Modelling of Airport Delay*. Evans. 2008.
- *Modelling Environmental and Economic Impacts of Aviation: Introducing the Aviation Integrated Modelling Project*. Reynolds et al. 2007.

Thank you