A System Dynamics Perspective of the Air Transportation Industry

Bruno Miller

John-Paul Clarke

Massachusetts Institute of Technology

Joint Universities Program Meeting, NASA-AMES

April 5th, 2002

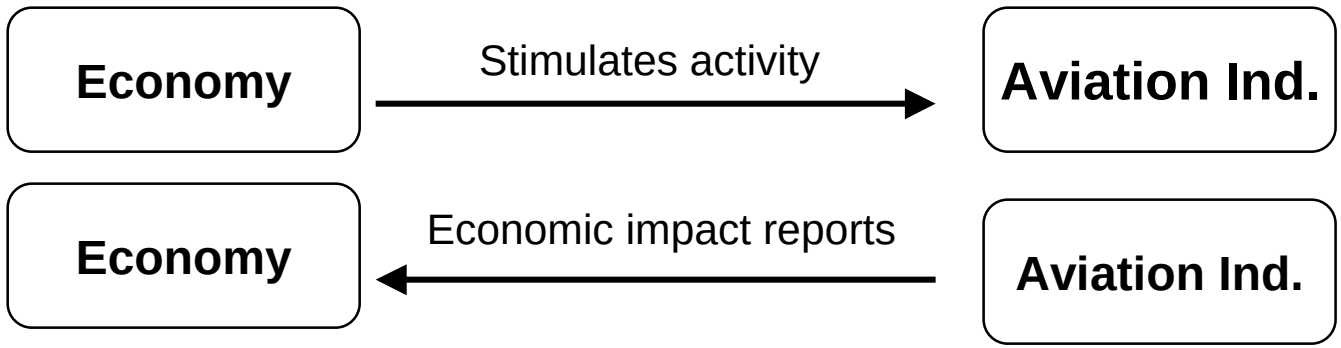
Motivation

- **The air transportation system is complex and is usually analyzed in pieces:**
  - ☐ airline profitability models
  - ☐ hub and spoke models
  - ☐ ATC models

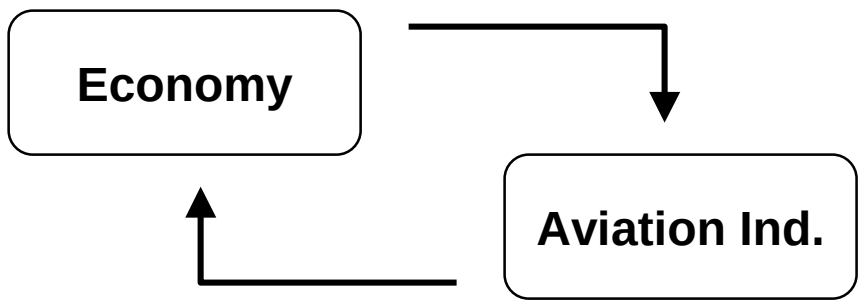
→ **Piecewise approach may lose some insights into the interrelations of the different components**

Motivation (2)

- **Relationship between aviation and the economy frequently studied in two ways:**



- **… but there is the need to understand the feedback mechanisms between the two:**



Objectives of this study

- **Develop a:**
  - ☐ top-level system dynamics model . . .
  - ☐ that considers air transportation as a whole . . .
  - ☐ and the feedback mechanisms between aviation and the economy . . .
  - ☐ to analyze the major interactions and identify the critical elements . . .
  - ☐ to guide air transportation decision-makers in the design of effective aviation policy

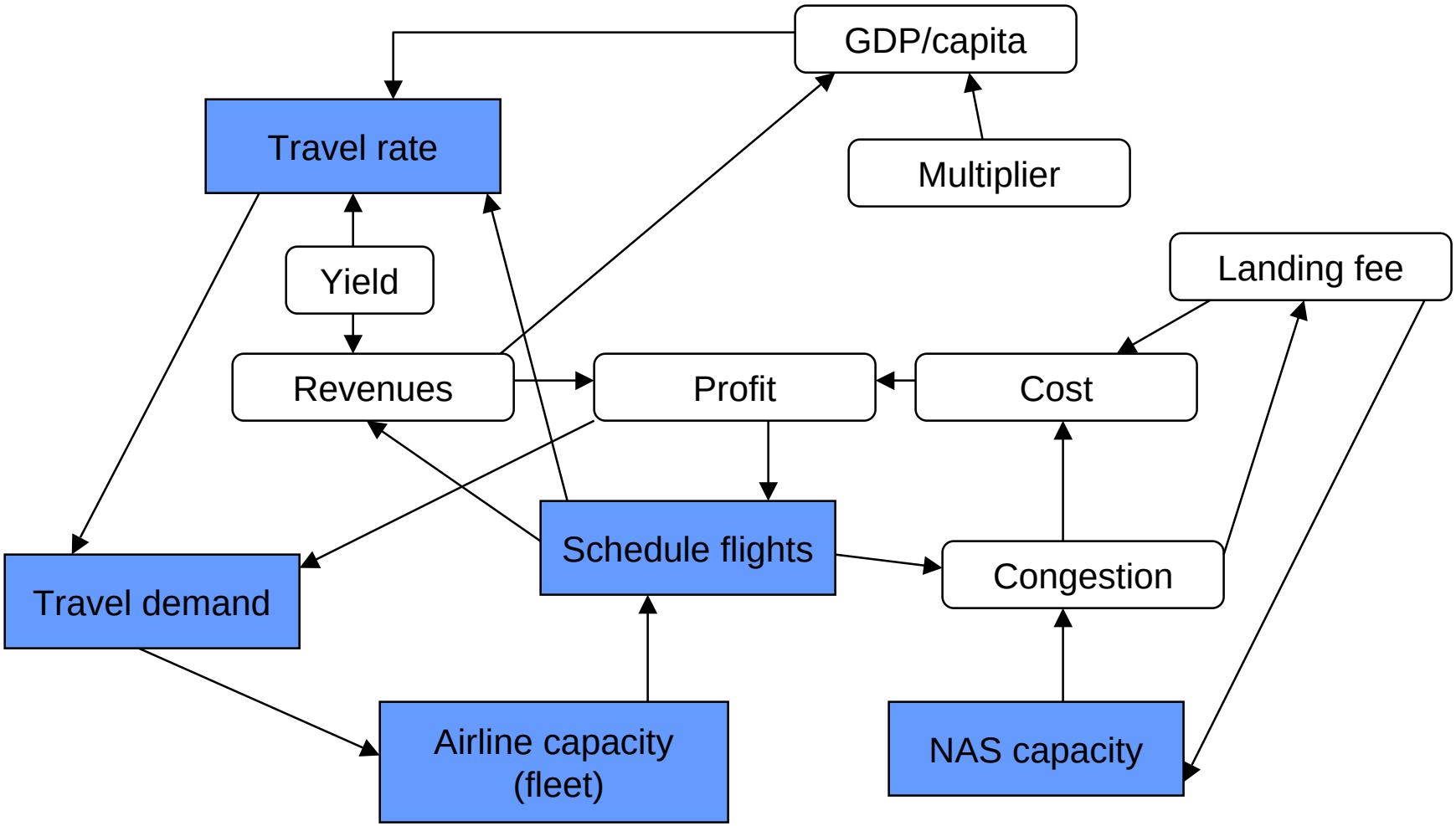
→ Responses to congestion in the national airspace system (NAS) is used as an example

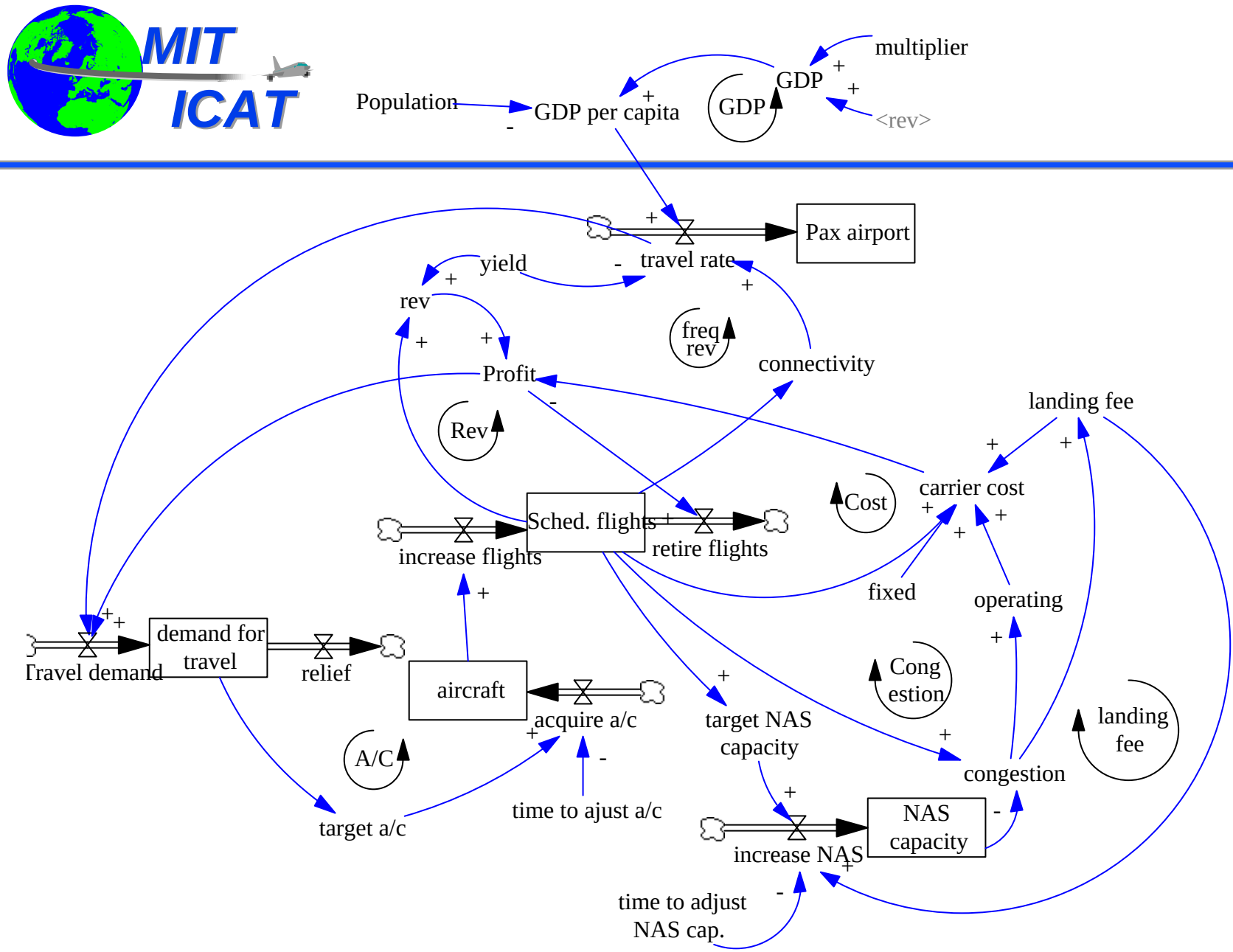
What is system dynamics?

- **A method to understand complex systems and how they change over time**
- **Focuses on how individual elements interact and affect the behavior of the entire system through feedback loops**
- **Its aim is to understand the structure of the system and understand the behavior it can produce**

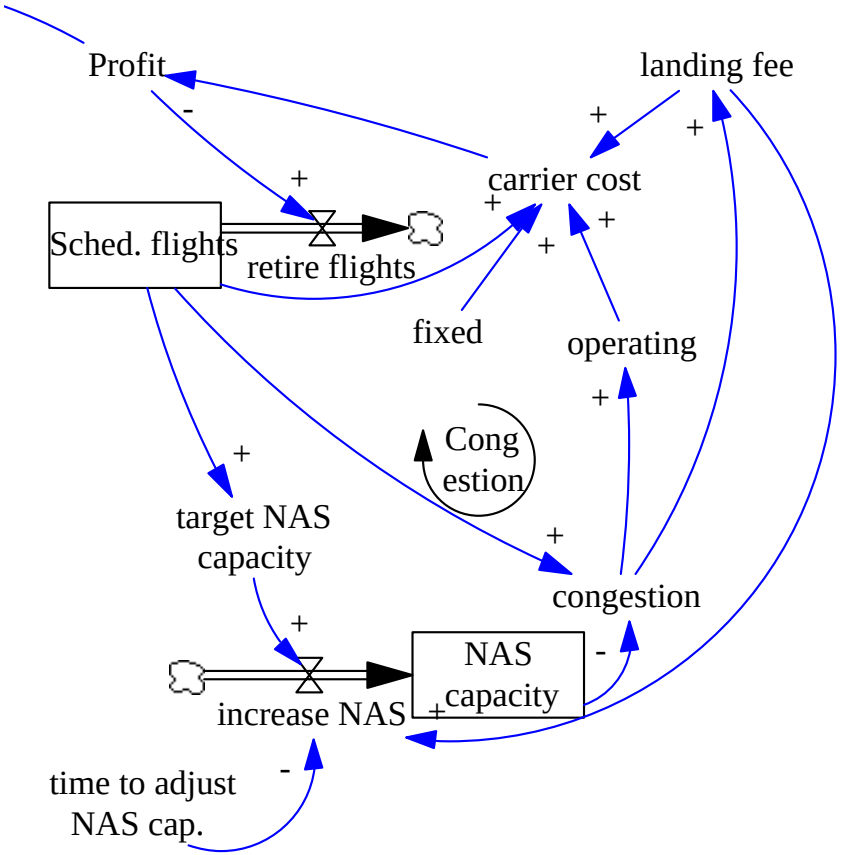
Source: http://sysdyn.mit.edu/

Air transportation system model




MIT
ICAT
Population
GDP per capita
GDP
multiplier
<rev>
Pax airport
travel rate
yield
rev
freq rev
connectivity
Profit
Rev
landing fee
carrier cost
Cost
Sched. flights
increase flights
retire flights
fixed
operating
Travel demand
demand for travel
relief
aircraft
acquire a/c
A/C
target a/c
time to ajust a/c
target NAS capacity
Cong estion
congestion
landing fee
NAS capacity
increase NAS
time to adjust NAS cap.

Key relationships



If Sched. Flights > NAS capacity:

- System increases NAS capacity at a pre-specified rate

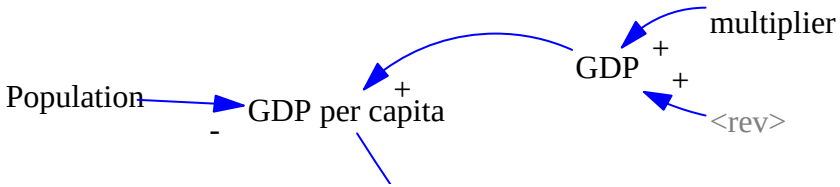
- 2 congestion pricing policies:

a) congestion increases op. costs, profits become negative, Sched. flights are reduced

b) congestion increases landing fee, which get reinvested in the NAS

- NAS capacity specified in RPM
- 1995 RPM levels taken as uncongested NAS capacity

Economic impact of air transportation



- **Traditional economic impact studies of aviation assume three types of effects:**
  - **Direct:** value of all economic activities directly attributed to aviation
  - **Indirect:** economic activity attributed to airline passengers and freight forwarding businesses
  - **Induced:** expenses by the recipients of income generated by the direct and indirect economic activities
- **Assume a multiplier to calculate induced effects from direct effects**

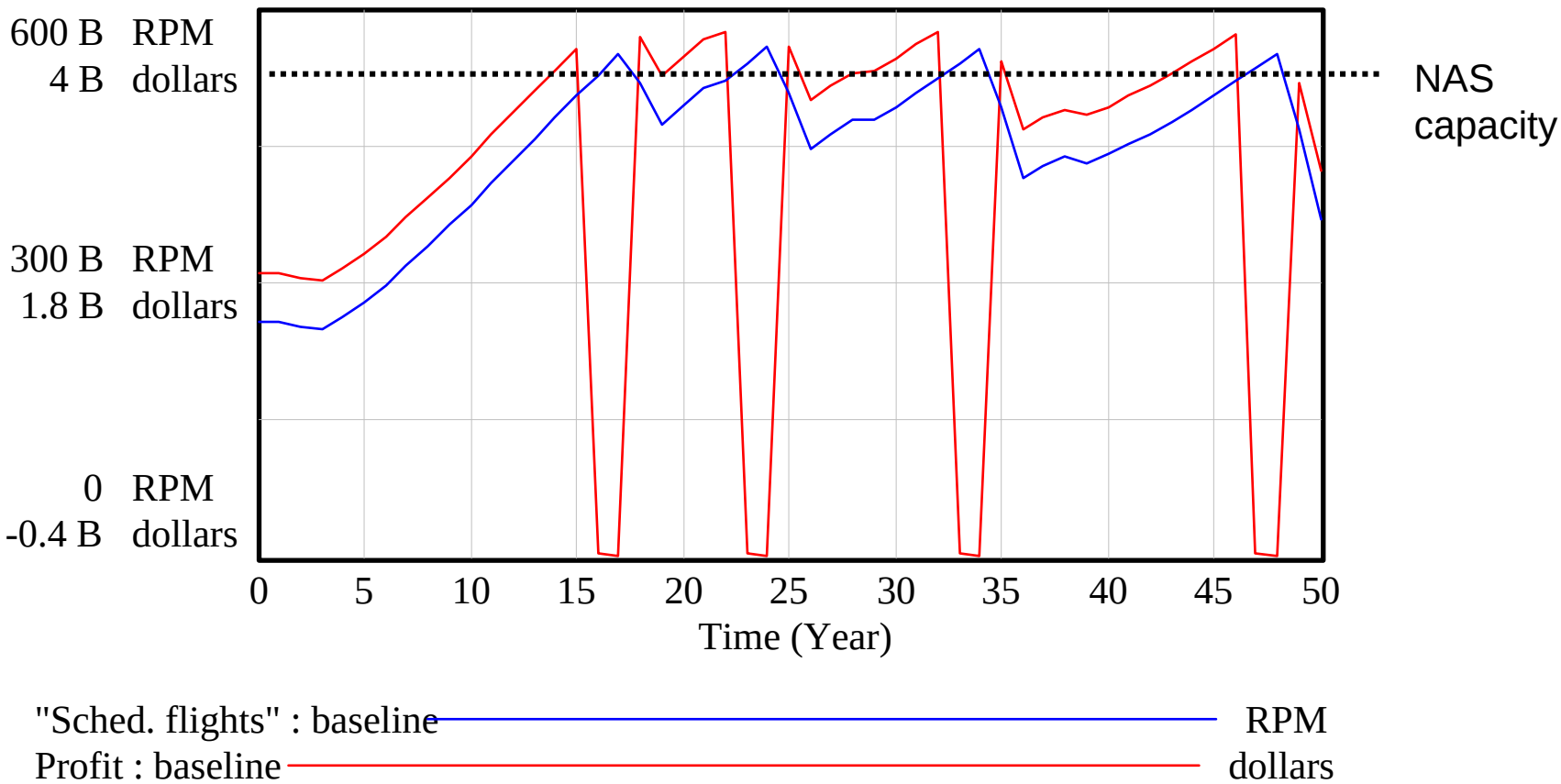
Model limitations

- **Industry aggregate**
- **Yearly data**
- **Fixed fares (yield)**

Baseline scenario

- **The following assumptions were made for the baseline scenario:**
  - NAS capacity (measured in RPMs) initially fixed at 1996 levels
  - If NAS capacity is exceeded,
    → congestion costs impact air carrier profits
    → if negative profits, scheduled flights are reduced by 10%
    → capacity is increased with an adjustment time of 15 years

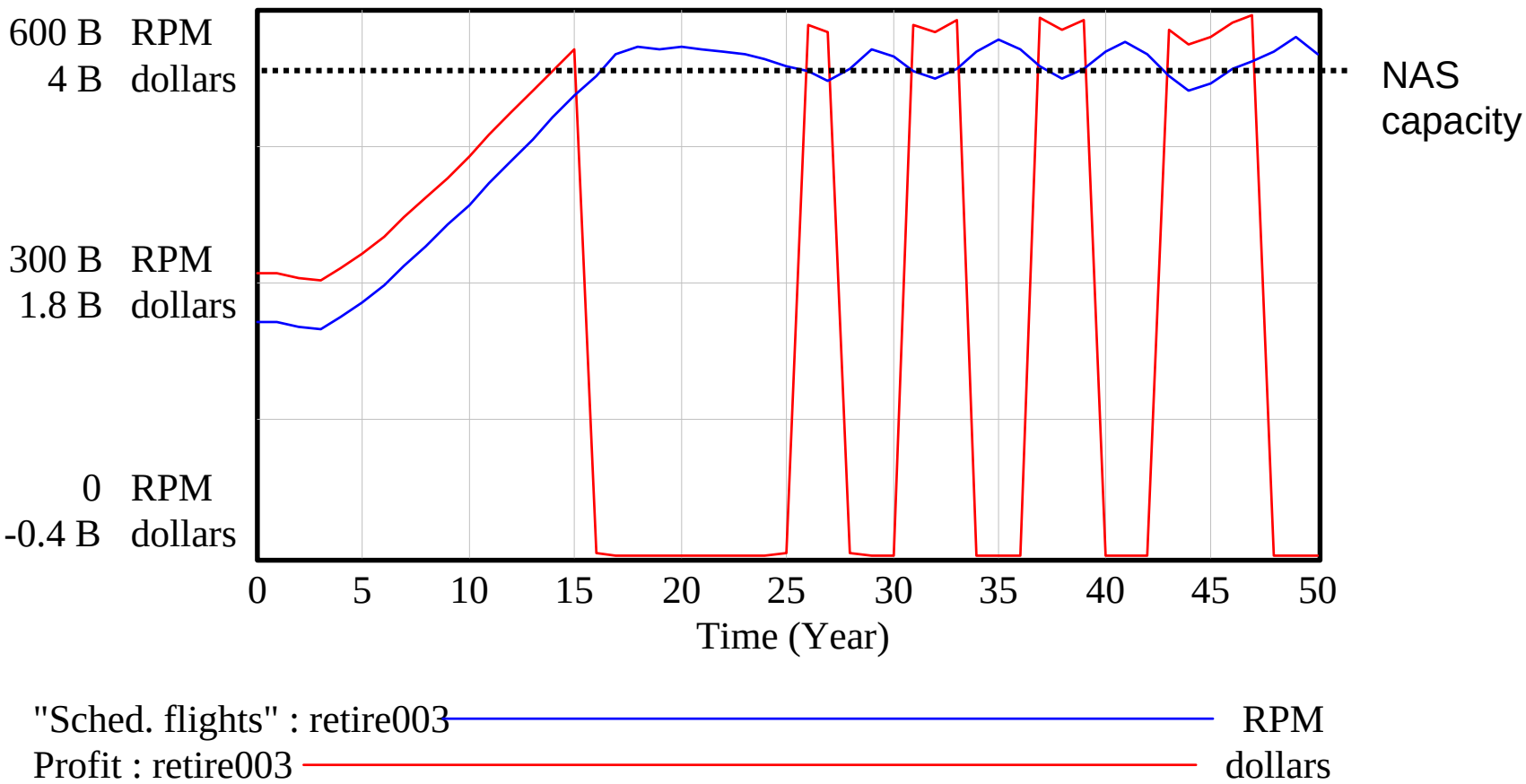
Airline response to congestion: retire 10% of flights



Airline response to congestion: retire 10% of flights (2)

- Starting in year 0 (1980), Profits (measured in $, red line) and Scheduled Flights (measured in RPM, blue line) grow without capacity problems
- Between years 15 and 16, Scheduled Flights exceed NAS capacity, congestion increases carrier costs and profits become negative
- Because the model is updated yearly, it is not until year 17 that a corrective measure (retirement of 10% of flights) is implemented and the desired result (reduction in congestion, positive profits) is not achieved until year 18
- The cycle repeats itself in subsequent years . . .

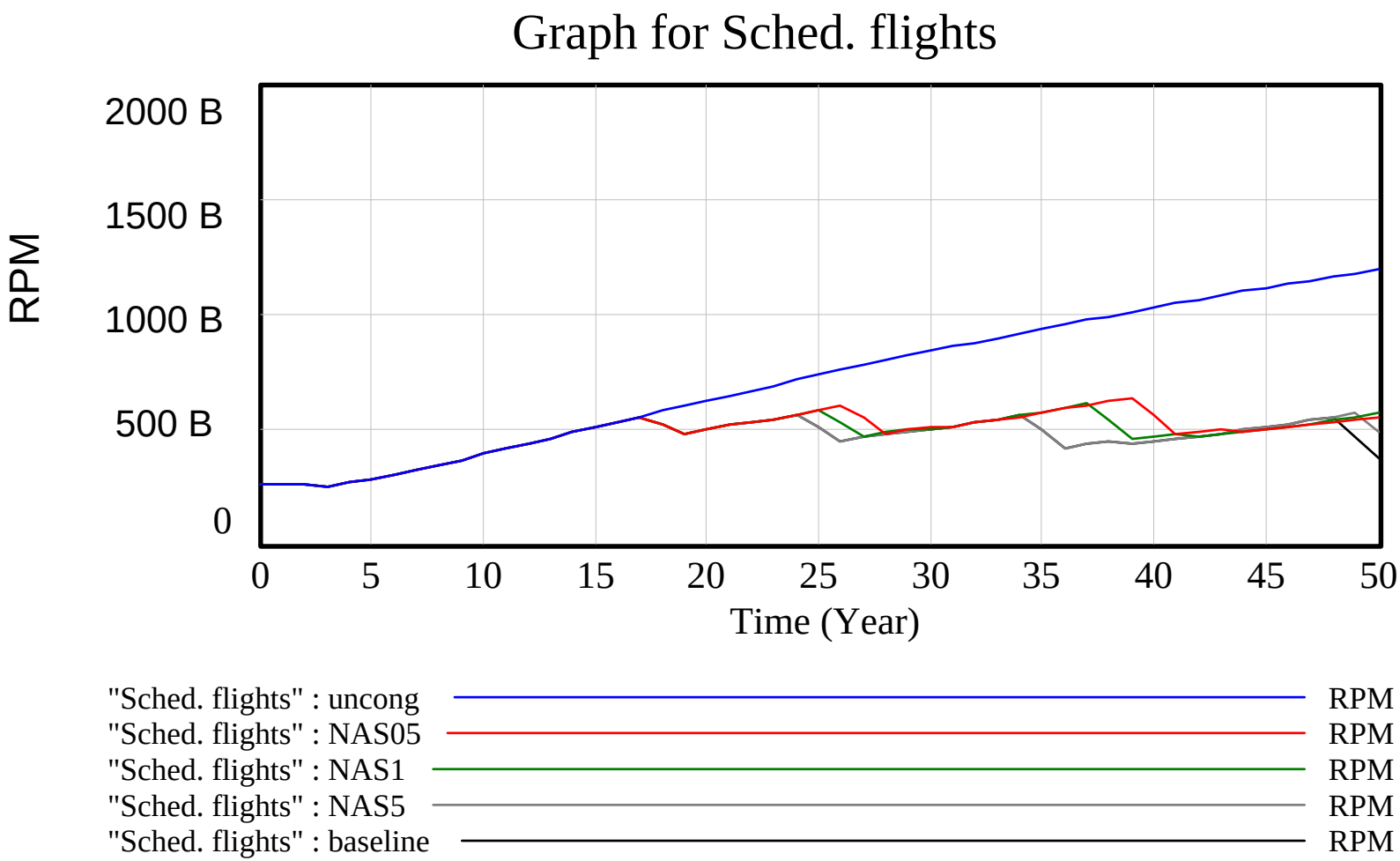
Airline response to congestion: retire 3% of flights



Airline response to congestion: retire 3% of flights (2)

- The same situation as before is observed here. Now, the corrective action is to retire 3% of the flights instead of 10%
- The result is a more stable system with the number of scheduled flights closer to NAS capacity
- The initial recovery of negative profits takes longer because the corrective action takes a few years to be effective

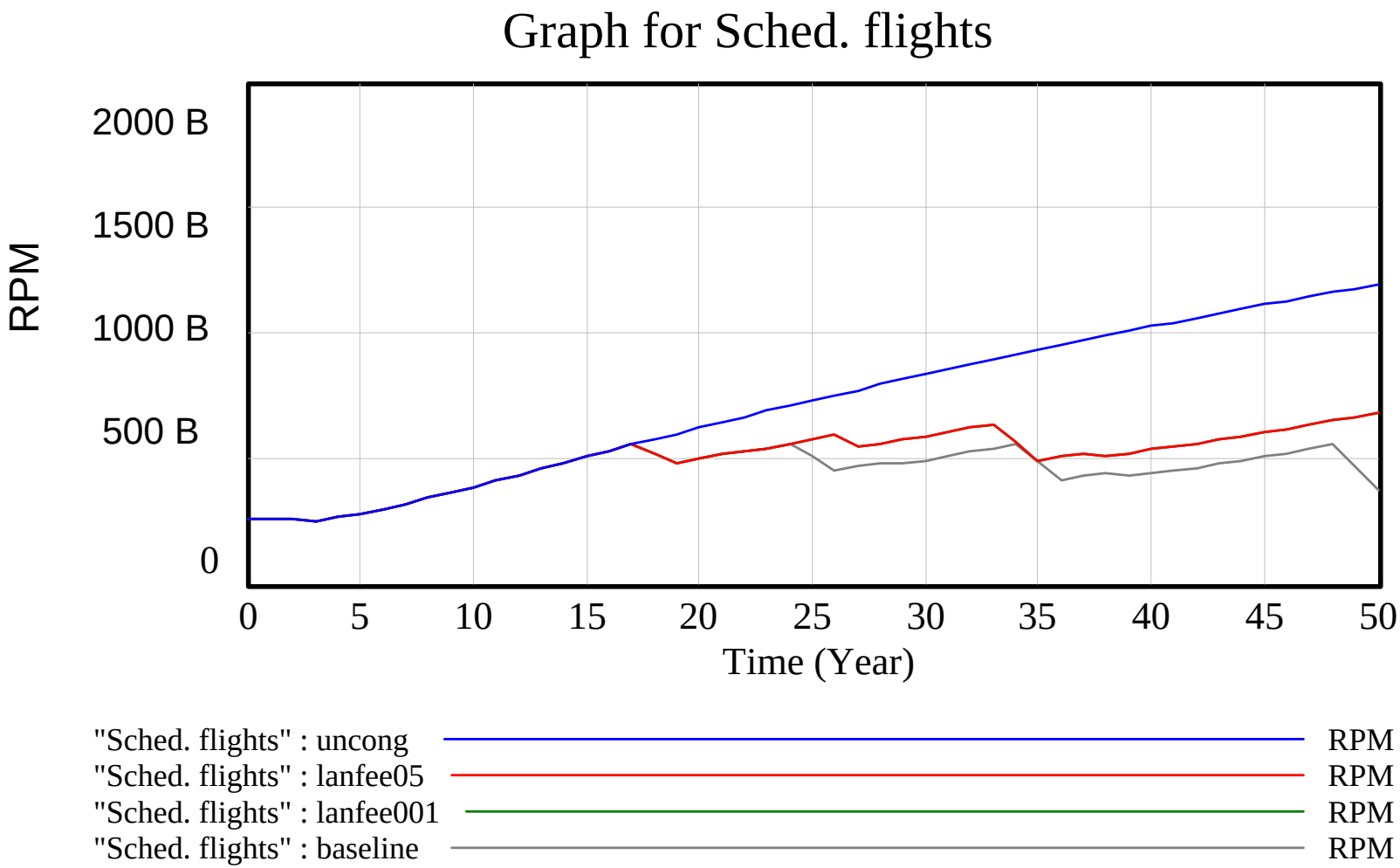
NAS response to congestion: reduce capacity adjustment time



NAS response to congestion: reduce capacity adjustment time (2)

- **As before, when scheduled flights exceed capacity, airlines retire flights and NAS capacity is increased at the baseline rate (15 years)**
- **At the same time, when NAS capacity is exceeded, the system increases capacity at the different rates depending on the scenario:**
    - Uncong: n/a (uncongested scenario: NAS capacity is always sufficient)
    - NAS05: half a year
    - NAS1: 1 year
    - NAS5: 5 years
    - Baseline: 15 years
- **This response is *reactive*: the system reacts to congestion, but does not build extra capacity for future periods**

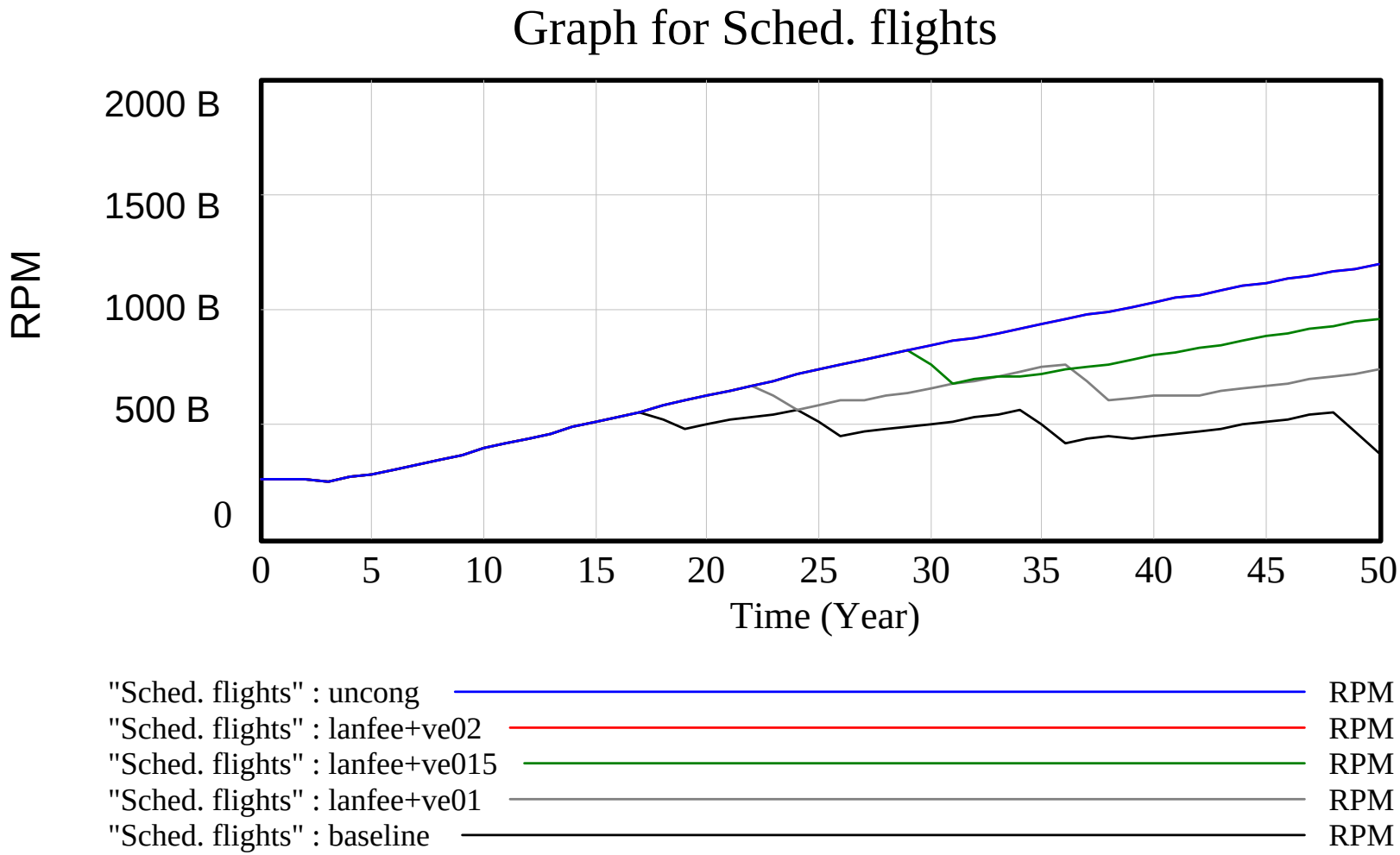
NAS response: use landing fees to increase capacity when congested



NAS response: use landing fees to increase capacity when congested (2)

- **As before, when scheduled flights exceed capacity, airlines retire flights and NAS capacity is increased at the baseline rate (15 years)**
- **In addition, extra NAS capacity is created with the direct use of funds from landing fees**
- **Several scenarios are contemplated:**
  - Uncong: uncongested
  - Lanfee05: the extra funds from landing fees allow a 5% increase in NAS capacity (hypothetical case for illustrative purposes)
  - Lanfee01: the extra funds from landing fees allow a 1% increase in NAS capacity (hypothetical case for illustrative purposes)
  - Baseline: no extra capacity is created with funds from landing fees

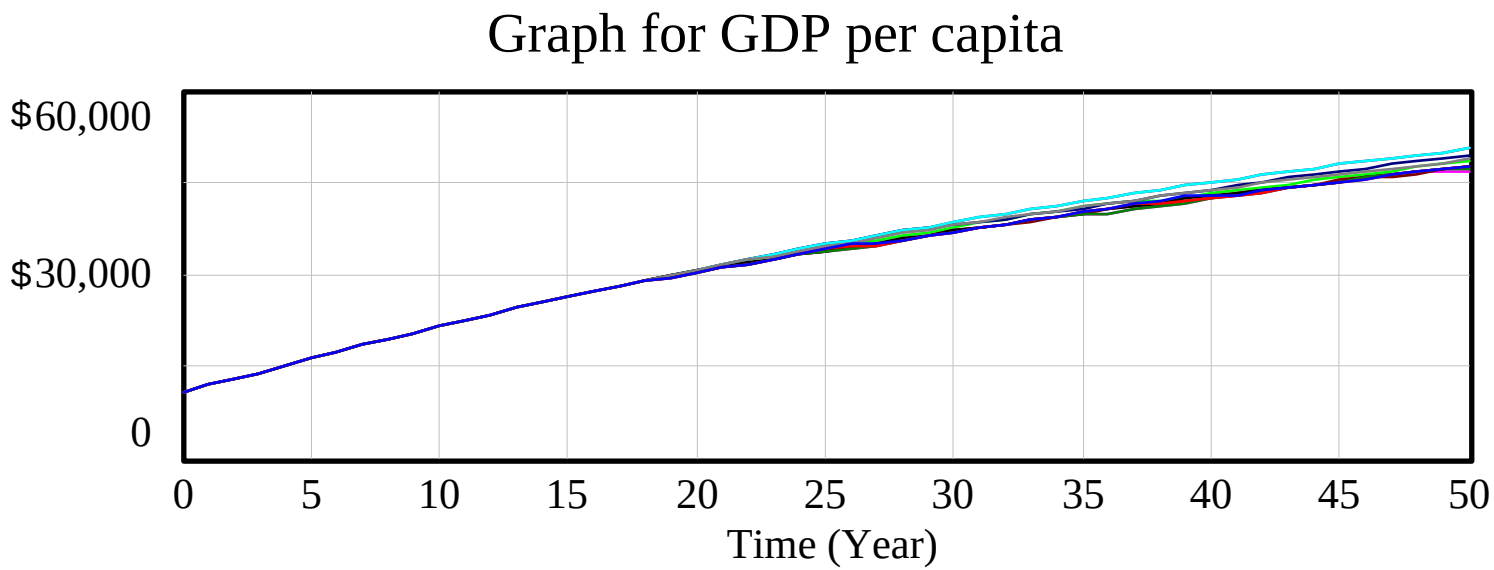
NAS response: use landing fees to increase capacity every year



NAS response: use landing fees to increase capacity every year (2)

- **As before, when scheduled flights exceed capacity, airlines retire flights and NAS capacity is increased at the baseline rate (15 years)**
- **Now, landing fees funds are used to increase capacity *every year* regardless of congestion**
- **The following scenarios are considered:**
  - Uncong: uncongested
  - Lanfee+ve02: 2% increase in NAS capacity every year with funds from landing fees
  - Lanfee+ve015: 1.5% increase in NAS capacity every year with funds from landing fees
  - Lanfee+ve001: 1% increase in NAS capacity every year with funds from landing fees
  - Baseline: no extra NAS capacity increase with funds from landing fees

Weak link between aviation and GDP per capita?



Weak link between aviation and GDP per capita (2)

- **Even though the study analyzes many different cases with different assumptions regarding retirement of flights, NAS capacity adjustment and use of funds from landing fees, there is no great variation in GDP per capita, suggesting a weak link between aviation and GDP per capita**

Conclusions

- **Systems dynamics is a useful tool to model the aviation industry and understand feedback mechanisms:**
  - Airline policy to reduce flights when profits are negative
  - Effect of decreasing NAS capacity adjustment time
- **Systems dynamics also useful to try aviation policy:**
  - Effect of using landing fees to increase NAS capacity on a yearly basis and on a as-needed basis
- **Weak link between air transportation and the economy (represented as GDP per capita):**
  - Traditional method of calculating the economic contribution of aviation with the use of multipliers may not capture complete benefits
  - Multiplier method does not account for productivity increases, establishment of new business transactions, etc
  - Multiplier method may not be relevant for a mature economy (e.g. US), but may be important for developing countries

Future work

- **Test quarterly data**
- **Consider other countries**
- **Disaggregate model: separate airlines with different cost and revenue structures (e.g. Southwest Airlines)**