System Dynamics of the Small Satellite Industry

Policy Recommendations for a New Space Economy

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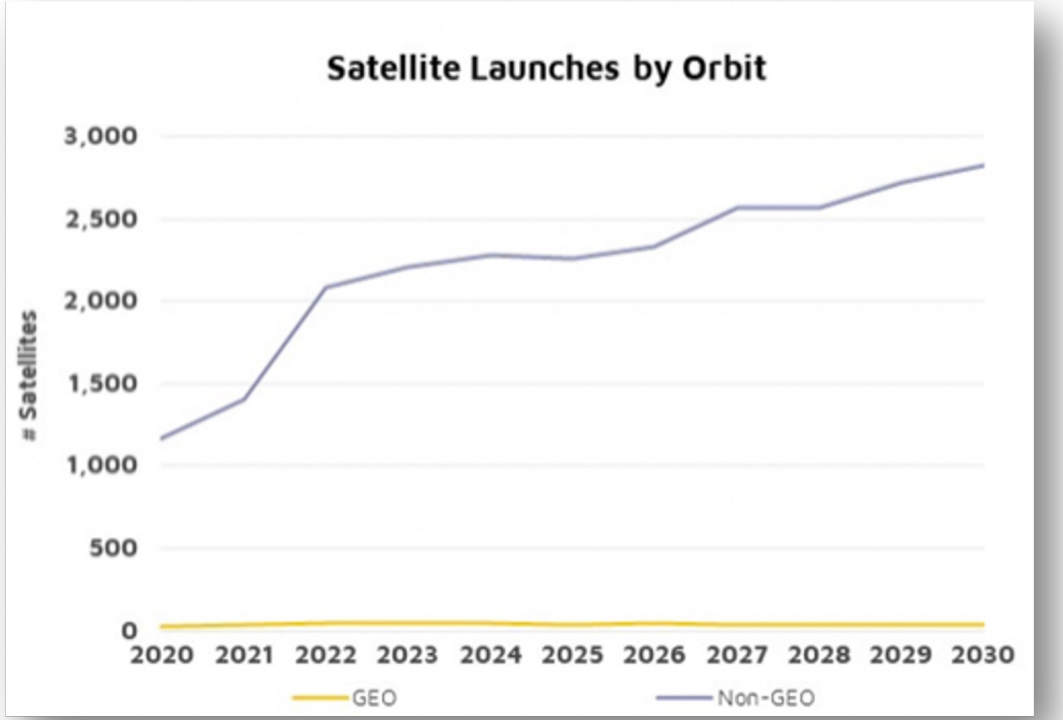
Summary – The Real Source of Risk

- Projections show exponential growth of active satellites
- Experts agree on potentially disastrous consequences
- Extensive research conducted in capacity and traffic management
- Proposals for sustainability from a technical and policy aspect

- **Problem:** No policy aimed at questioning risk of economic viability
- **Our aim:** To develop a comprehensive diffusion model to advise a real-option based licensing policy

Projections: 10x active satellites by 2030

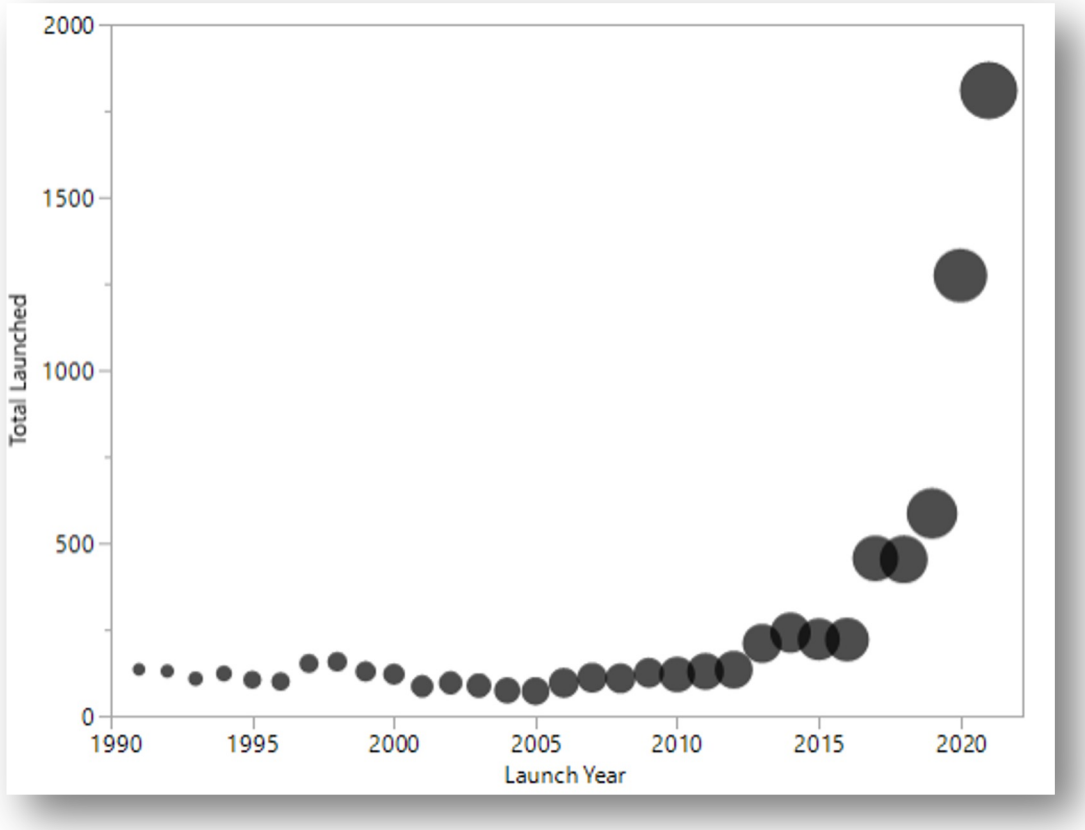
- Conservative estimates predict 30-50000
- Increase in active satellites is 10x
- Satellite population dominated by LEO satellites
- Largest percentage will be commercial
- Actual numbers likely much higher



Source: NSR

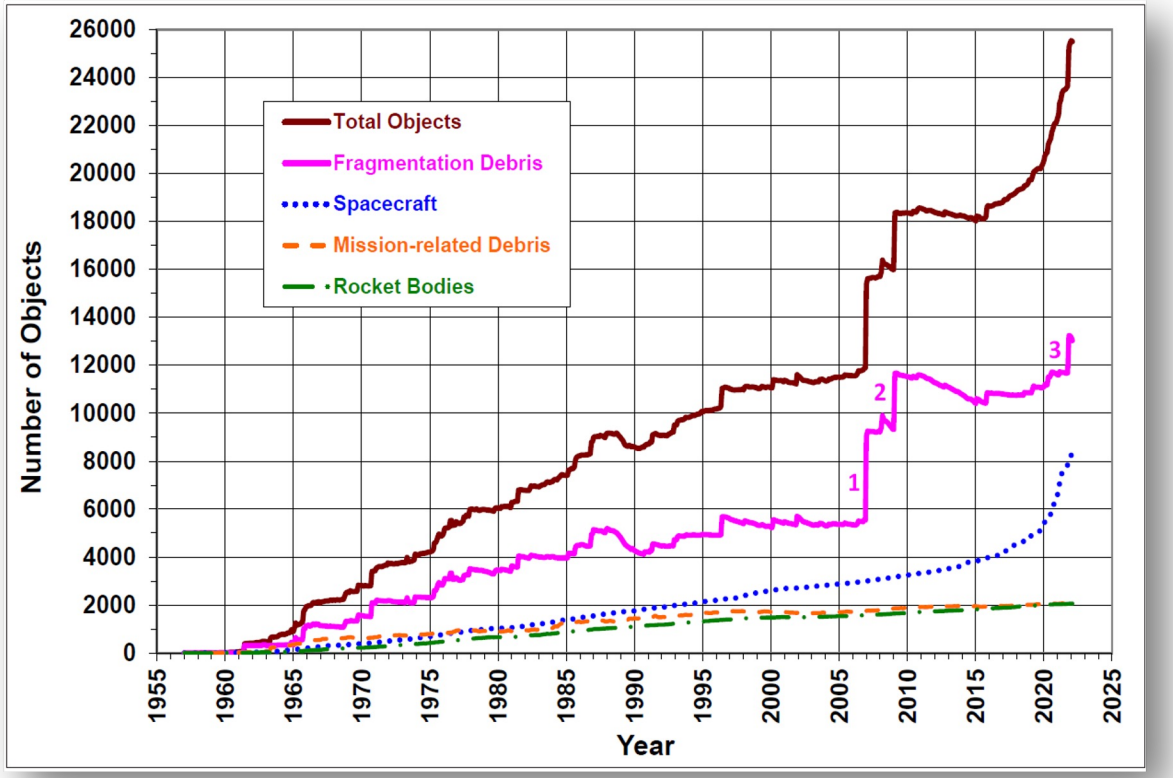
Because You Can: Effect of Launch Costs

- Reusable rockets reduced launch costs
- 90’s cost/kg baselined to Shuttle launch
- 2021 cost/kg baselined to Falcon launch
- Bubble size: cheaper launch larger bubble
- Technology push still dominates



Potential Impacts: Collisions & Cascading

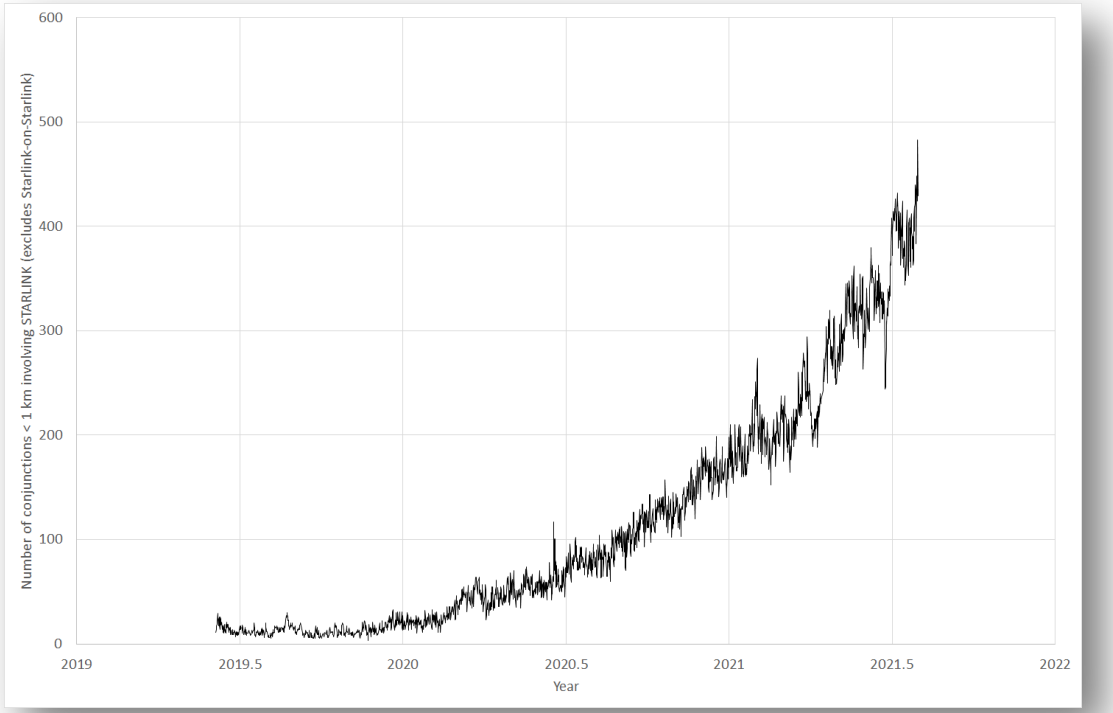
- Congestion due to increase in RSOs
- Greater risk of collisions
- Greater risk of cascading events (Kessler)
- Single collision can 2x-3x debris
- Previous collisions occurred at lower density



Source: NASA

Present Consequences: Conjunction Alerts

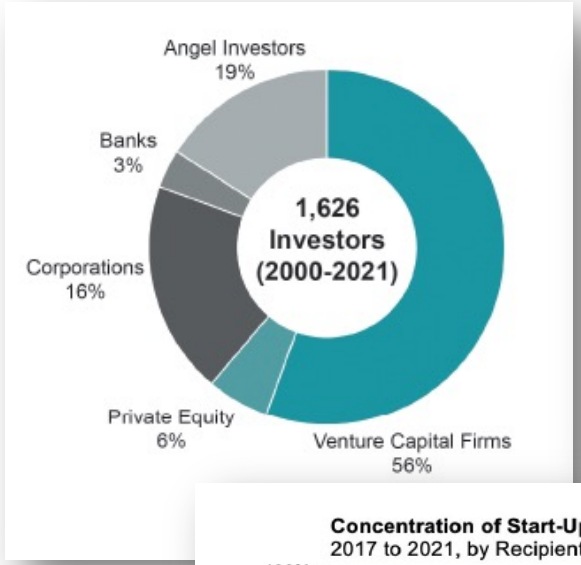
- Congestion already increases costs
- Conjunction alerts (CA) increased exponentially
- Majority of CA due to debris and constellations
- Most CA involve single operator
- CA increase imposes costs on all operators

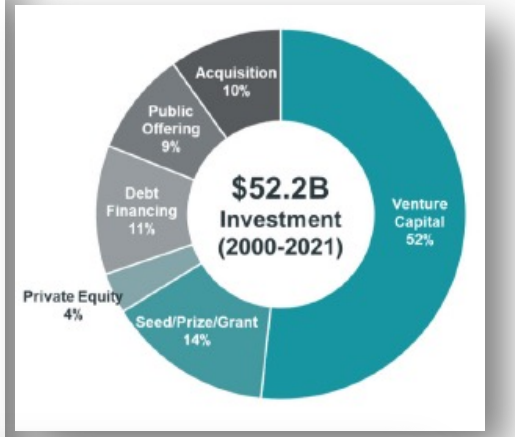


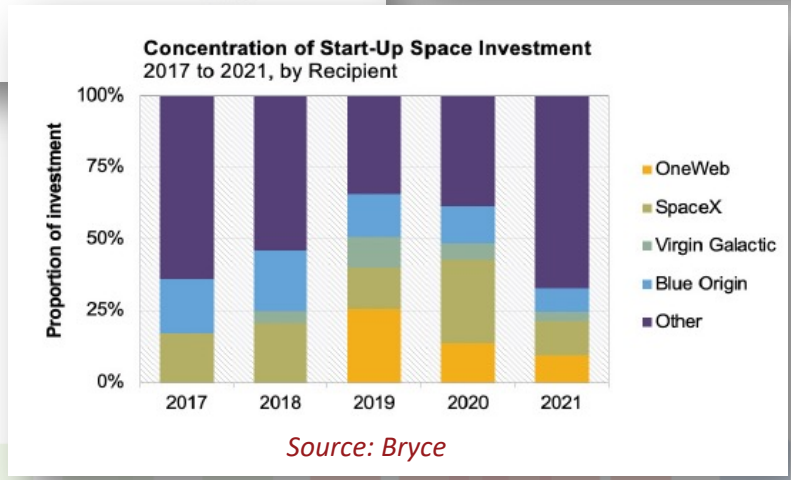
Source: Professor Hugh Lewis

Source of Growth: Tech. Push *Financial* Pull

- Large portion of funding from VCs
- Investments focused on constellations
- Business models focused on growth
- "Self-fulfilling" growth models
- Technical push and *financial* pull







Source: Bryce

Sound Technical, Weak(er) Market Justification

- Growth of LEO telecom companies
- Solid proof of technical aspects
- Weak justification of business side
- Yet no impact on growth
- No impact on *licensing*

Aerospace & Defense

Musk says may need $30 bln to keep Starlink in orbit

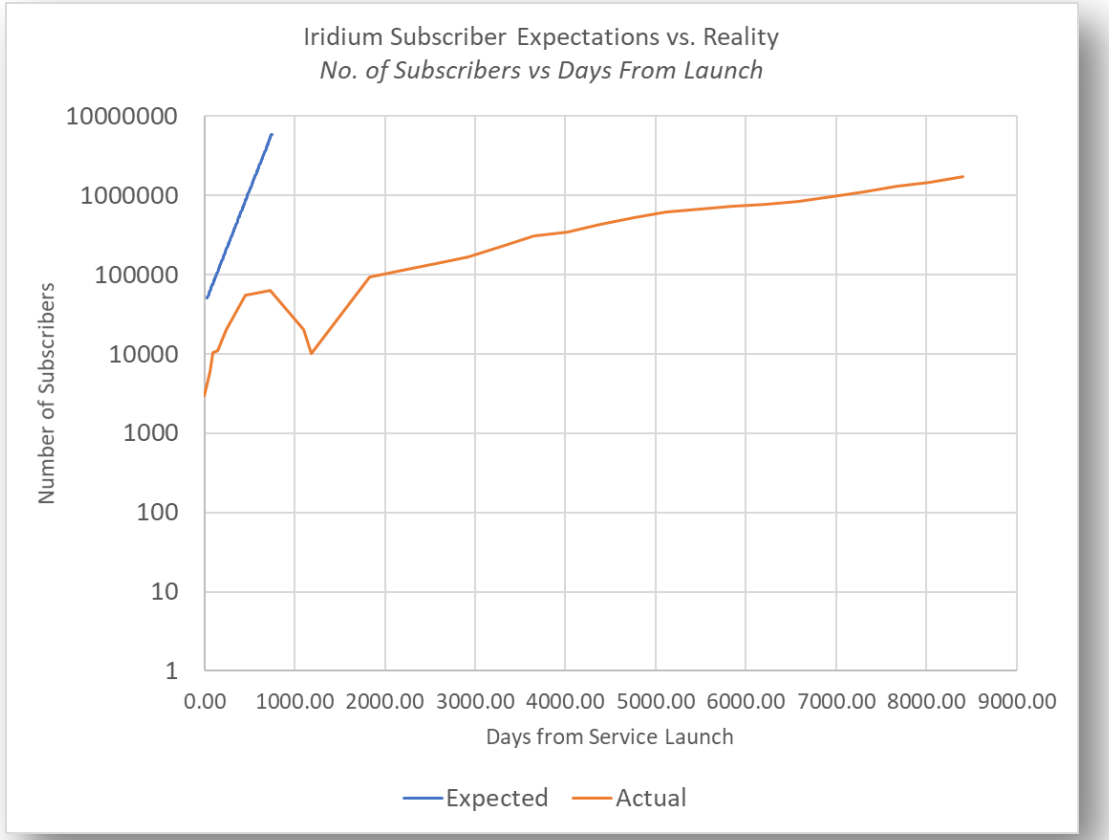
By Supantha Mukherjee and Clara-Laeila Laudette

BARCELONA, June 29 (Reuters) - Billionaire entrepreneur Elon Musk said on Tuesday that his Starlink satellite internet venture was growing quickly as he forecast total investment costs in the business at between $20 billion and $30 billion.

Source: Reuters

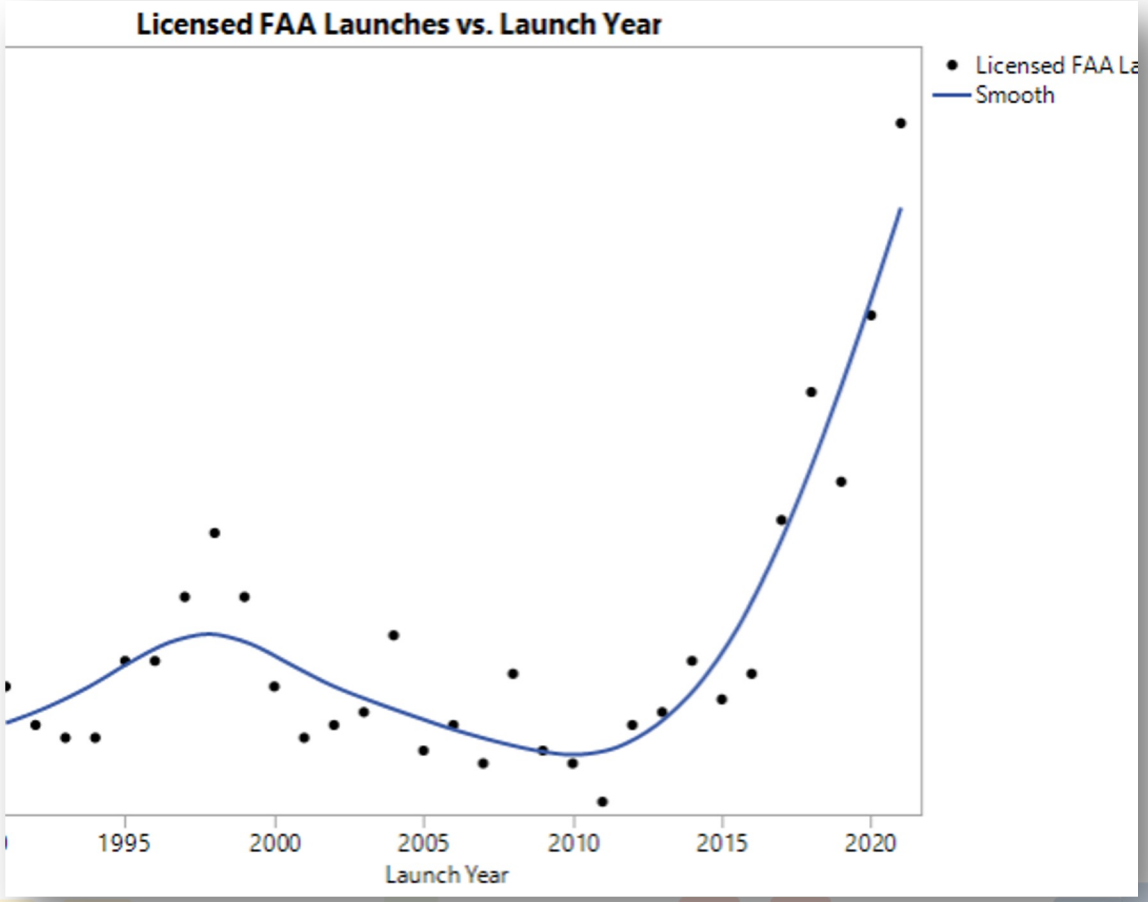
Consequences of Weak Business Models

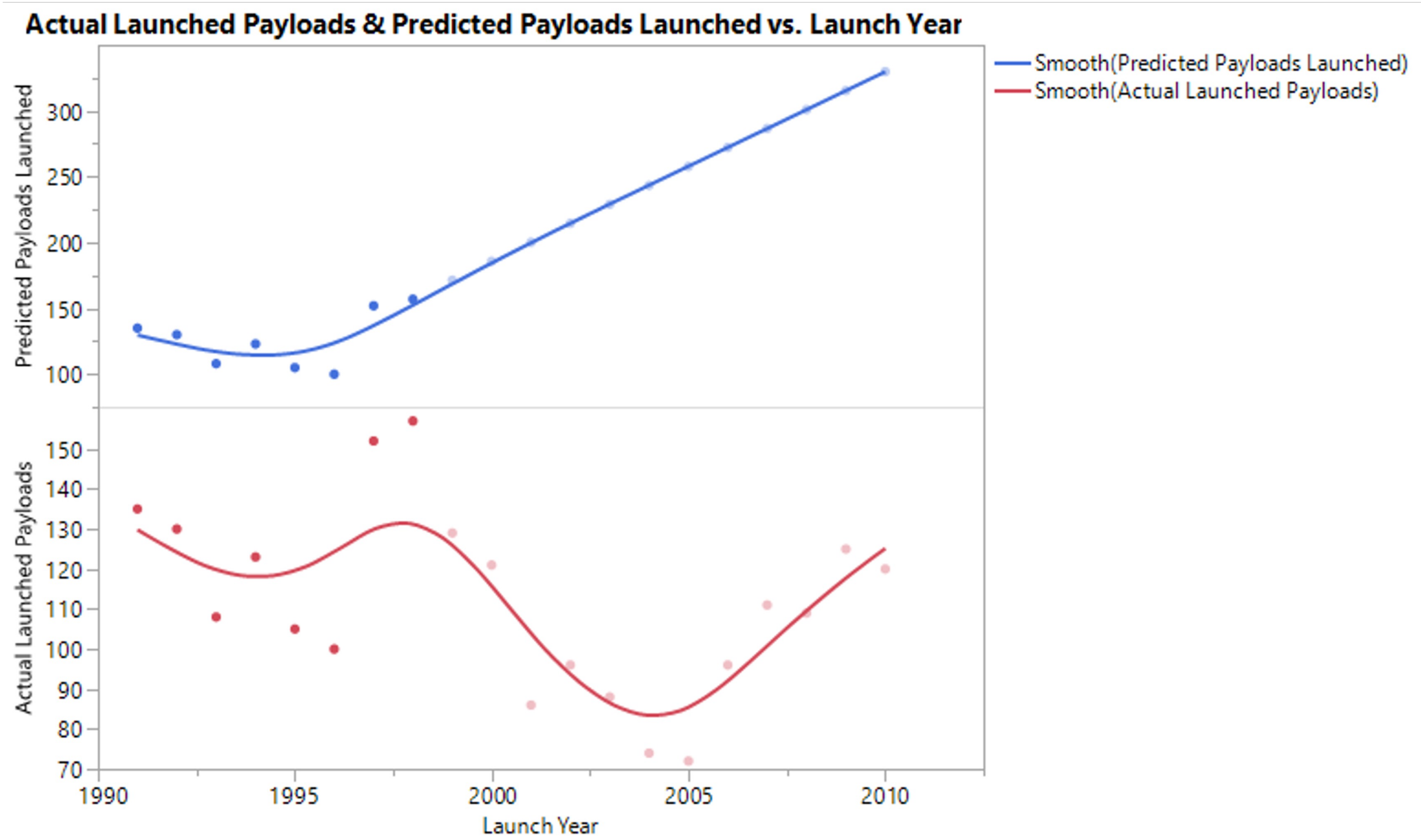
- Most known example: Iridium
- Original subscriber expectations still not reached
- Escalation of commitment clouded forecasts
- Crash lead to fall out in space funding
- More conservative assumptions than today



Iridium: Industrial Fallout

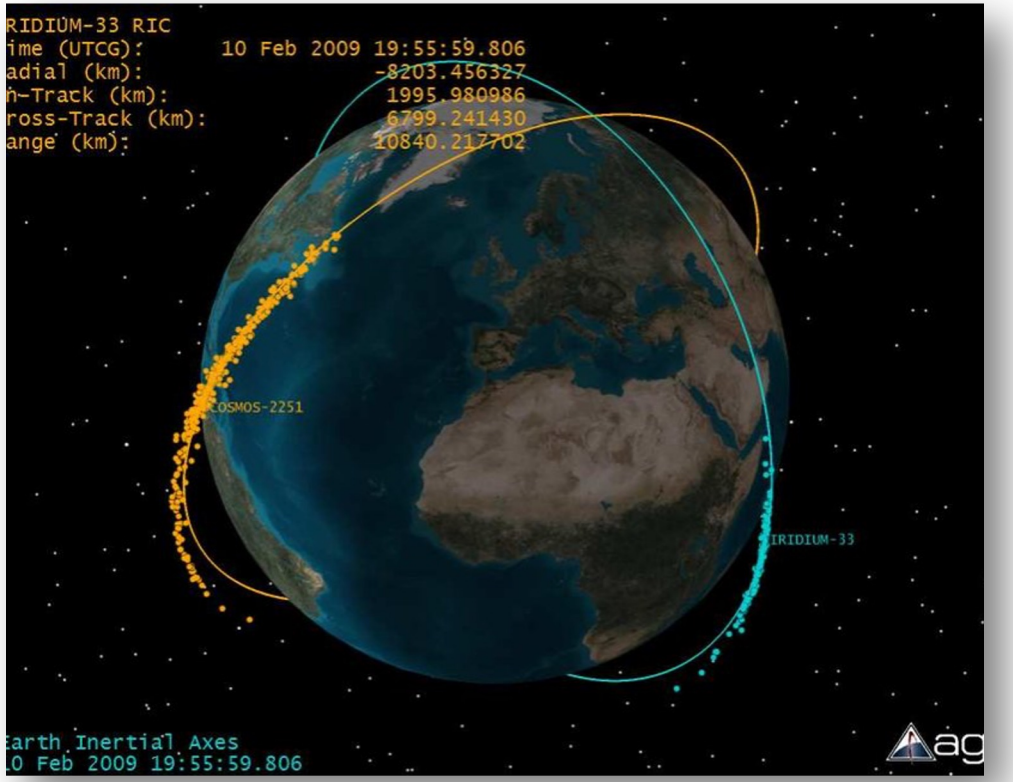
- Iridium's failure was of "cosmic" scale
- One of 20 largest Chapter 11 filings
- Reduction in launches for decades
- Reduction in funding for a decade




Actual Launched Payloads & Predicted Payloads Launched vs. Launch Year
Smooth(Predicted Payloads Launched)
Smooth(Actual Launched Payloads)
Predicted Payloads Launched
300
250
200
150
100
Actual Launched Payloads
150
140
130
120
110
100
90
80
70
1990
1995
2000
2005
2010
Launch Year

Iridium: Liability of an Operator

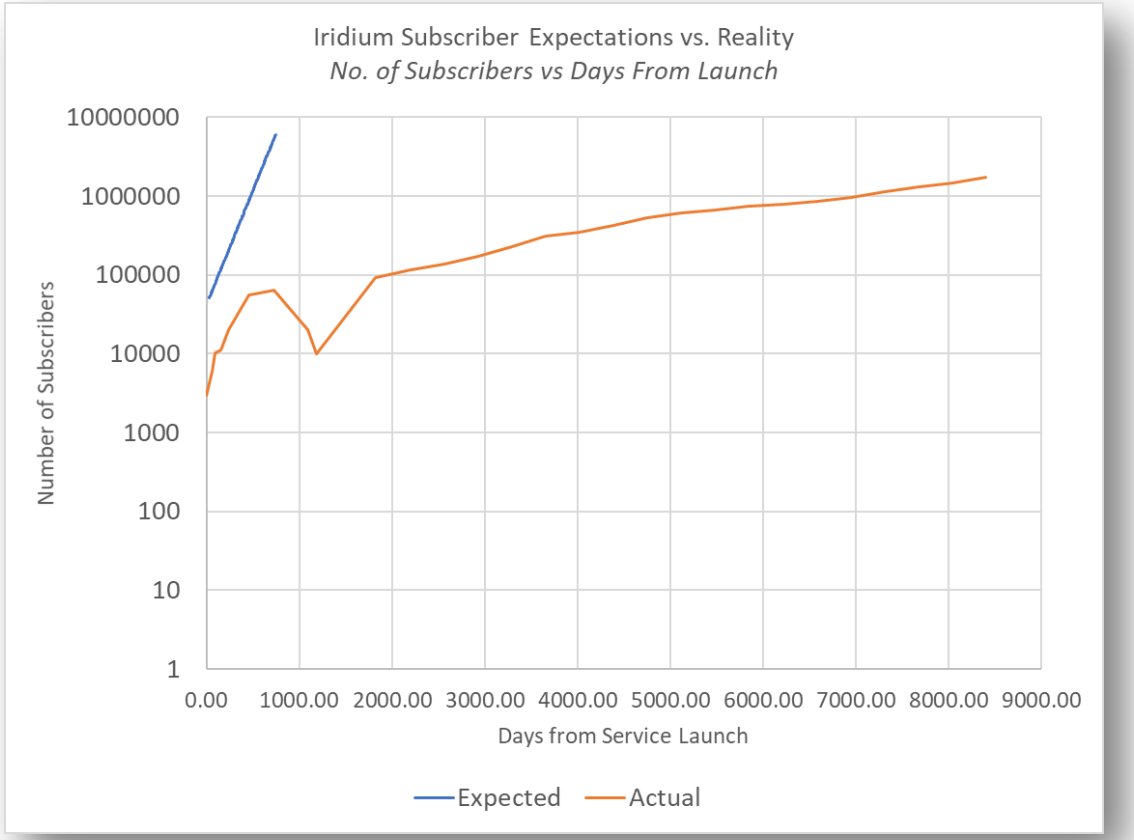
- Less discussed is real “cosmic” effect
- Largest collision to date involved Iridium
- Iridium spokesperson denied liability
- Overwhelming number of CA reported
- Question of liability in resourcing

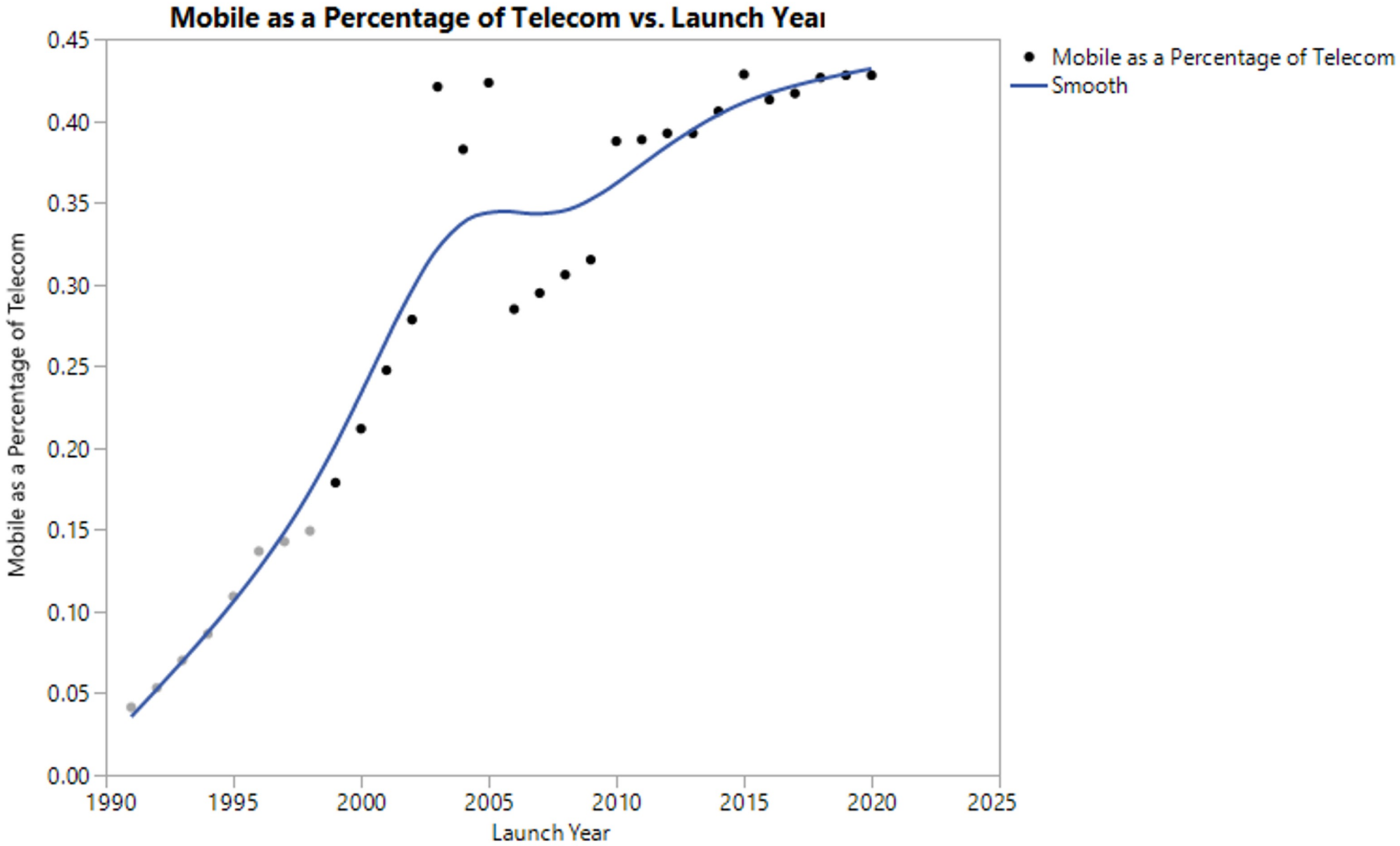


Source: AGI

Iridium: Poorly Understood Dynamic Environment

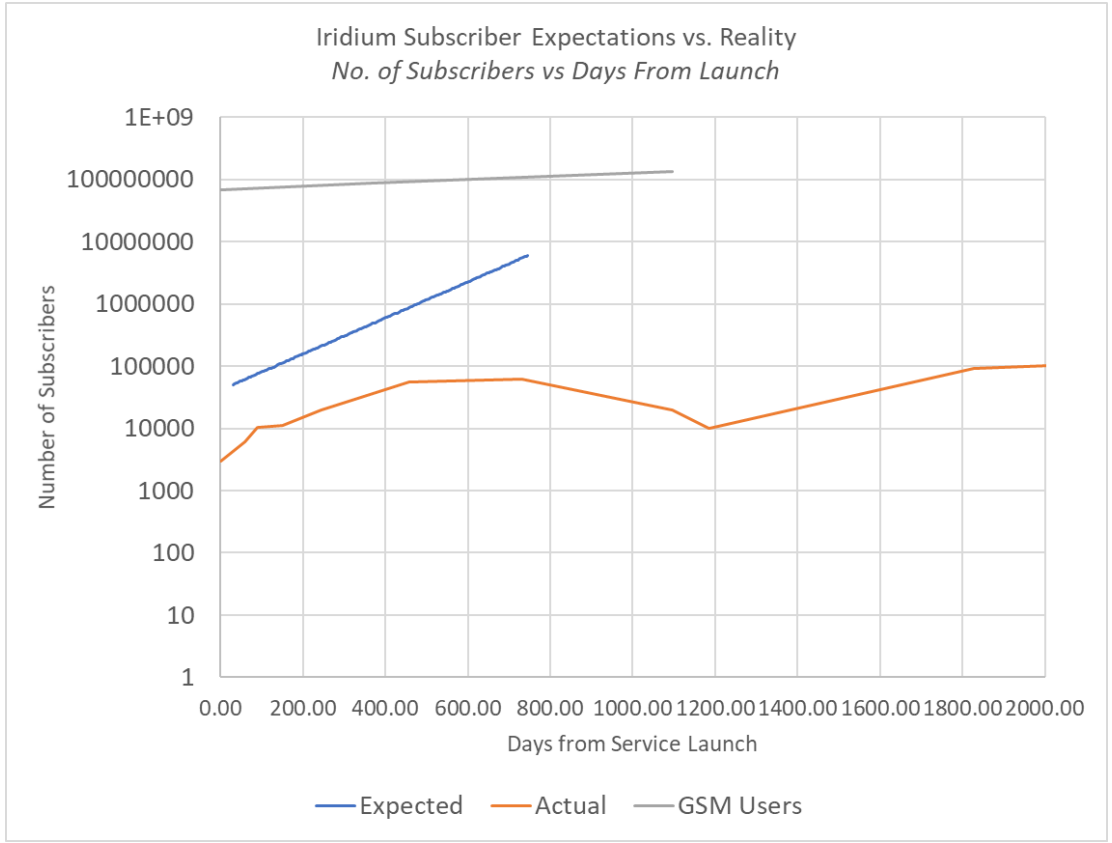
- Primary reason for Iridium's failure: alternatives
- Generally poorly understood market dynamics
- Tech. capabilities and flashy narrative
- Inflexible technology overtaken by alternatives
- Locked in capital had disastrous effects

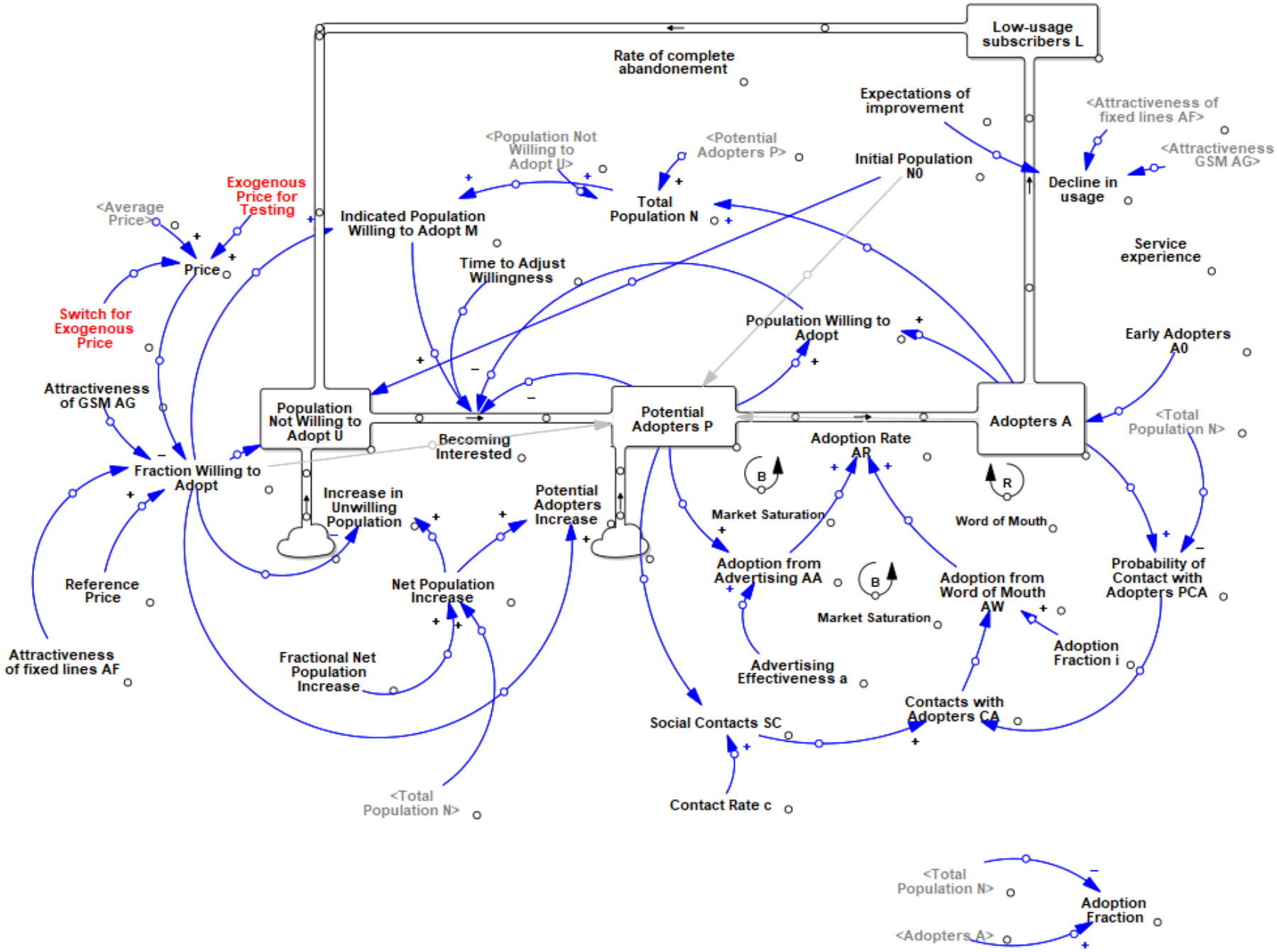



Mobile as a Percentage of Telecom vs. Launch Year
Mobile as a Percentage of Telecom
Smooth
Mobile as a Percentage of Telecom
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1990
1995
2000
2005
2010
2015
2020
2025
Launch Year

Iridium: Prime Example of Failed Diffusion

- Innovation diffusion can explain Iridium failure
- Iridium never reached expected “tipping point”
- Networked effects for logistic growth existed
- Alternatives and product issues led to collapse
- Fast collapse due to investor feedback loops




Low-usage subscribers L
Rate of complete abandonement
Expectations of improvement
<Attractiveness of fixed lines AF>
<Attractiveness GSM AG>
Decline in usage
<Population Not Willing to Adopt U>
<Potential Adopters P>
Initial Population N0
Total Population N
Indicated Population Willing to Adopt M
Exogenous Price for Testing
<Average Price>
Price
Time to Adjust Willingness
Service experience
Switch for Exogenous Price
Population Willing to Adopt
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<Total Population N>
Becoming Interested
Adoption Rate AR
Fraction Willing to Adopt
Increase in Unwilling Population
Potential Adopters Increase
Market Saturation
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Probability of Contact with Adopters PCA
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Adoption Fraction i
Contacts with Adopters CA
Social Contacts SC
<Total Population N>
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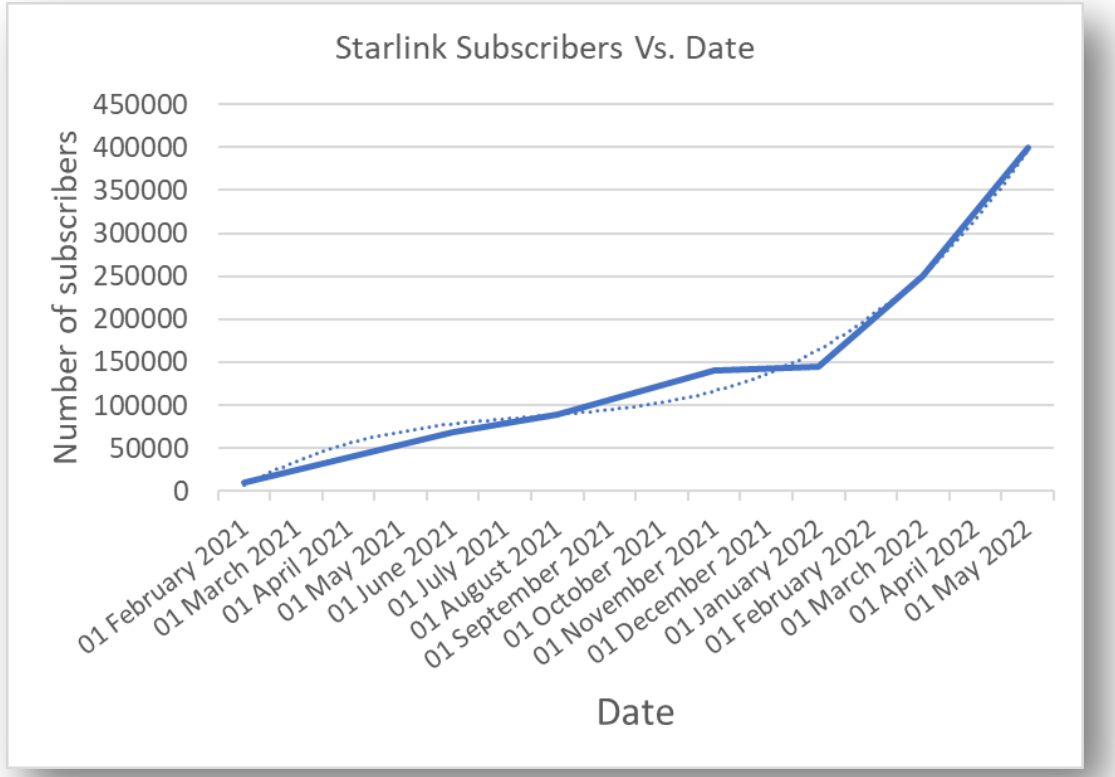
Adoption Fraction

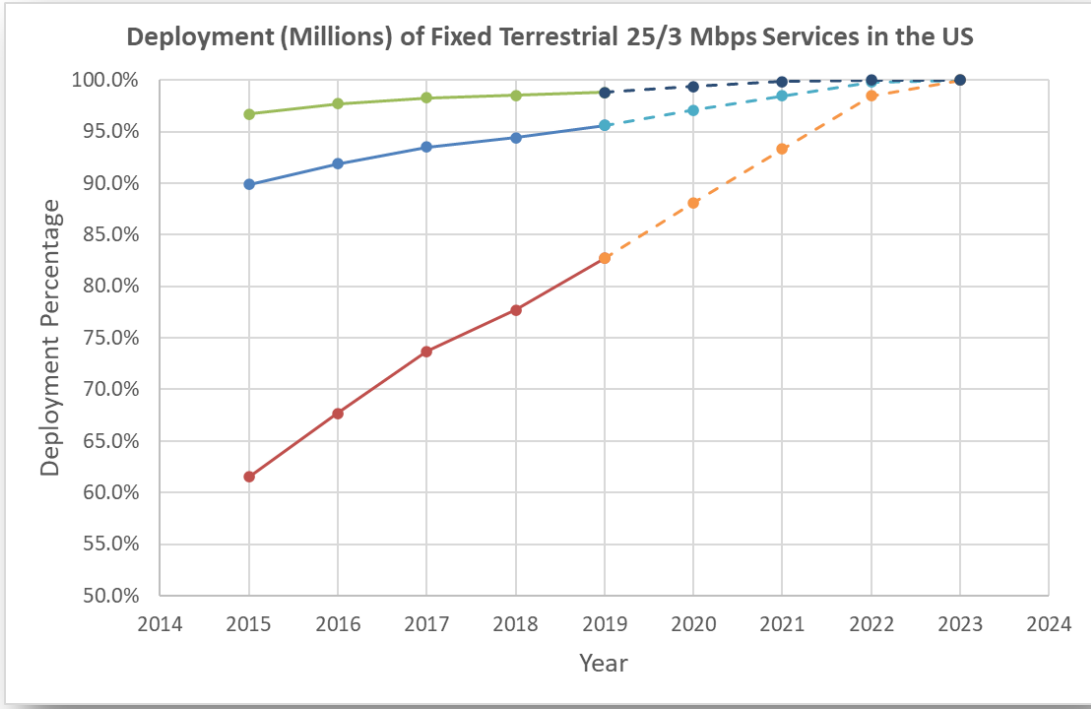
Does History Repeat Itself?

- LEO comms constellations: better business case
- Faster growth seen at least in Beta users
- Significantly greater scale of endeavour
- Greater potential fallout in all aspects
- Business models still not part of evaluation



Alternatives to Constellation Models Today

- LEO comms focused on rural/last-3billion demand
- Business models assume almost static alternatives
- Reality is fast spread of broadband
- Near prohibitive costs also contrast assumptions
- Collapse would lead to disastrous fallout



Research Focus on Orbital and Spectral Commons

- Growing acceptance of space as orbital commons
- Market already indicates issues of spectral scarcity
- Research primarily target orbital commons problem
- Frequency allocation is contested in courts
- Yet reality is increasing launch cadence due to FCC

Broadband Government/Military

NASA, Amazon, Satellite Operators Take Issue with SpaceX Starlink Gen-2 in FCC Filings

By Rachel Jewett | February 10, 2022

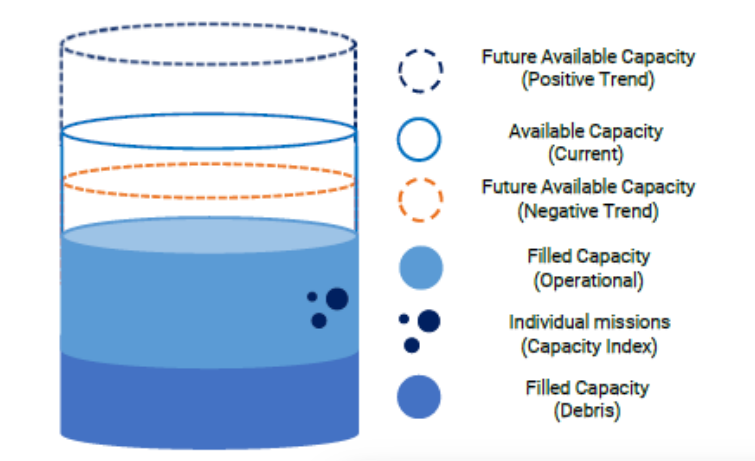
Broadband Government Spectrum

Starlink satellites before deployment on SpaceX's March 24 Falcon 9 mission. Screenshot via SpaceX.

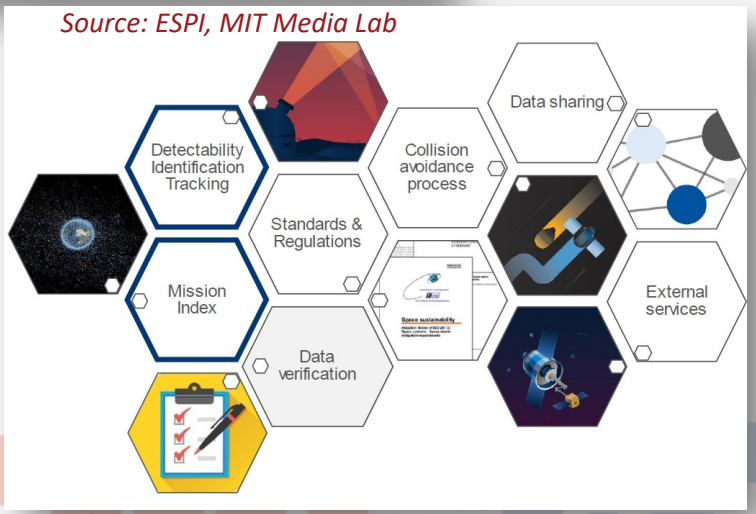
Source: Satellite Today

Solutions Focused on Sustainability Rooted in Tech

- Solutions primarily consider collision risk
- Tech solutions such as active removal or STM
- Policy solutions focusing on standards
- Licensing requirements do include collision risk
- Novel concepts such as SSR or Capacity Index



Source: ESPI, MIT Media Lab



No Assessment of Economic Viability

- No licensing or forecasting looks at economic viability
- Greater risk than all other sources of risk
- Only consideration is of economic impact of debris
- Licensing in all aspects should be contingent to viability
- Recommended that FCC reviews licensing process

Recommended Framework of Economic Risk

Spatial and Temporal Forecasting

- Accurate time-series forecasting of alternatives in all domains
- Spatial forecasting of demand

System Dynamics for Diffusion

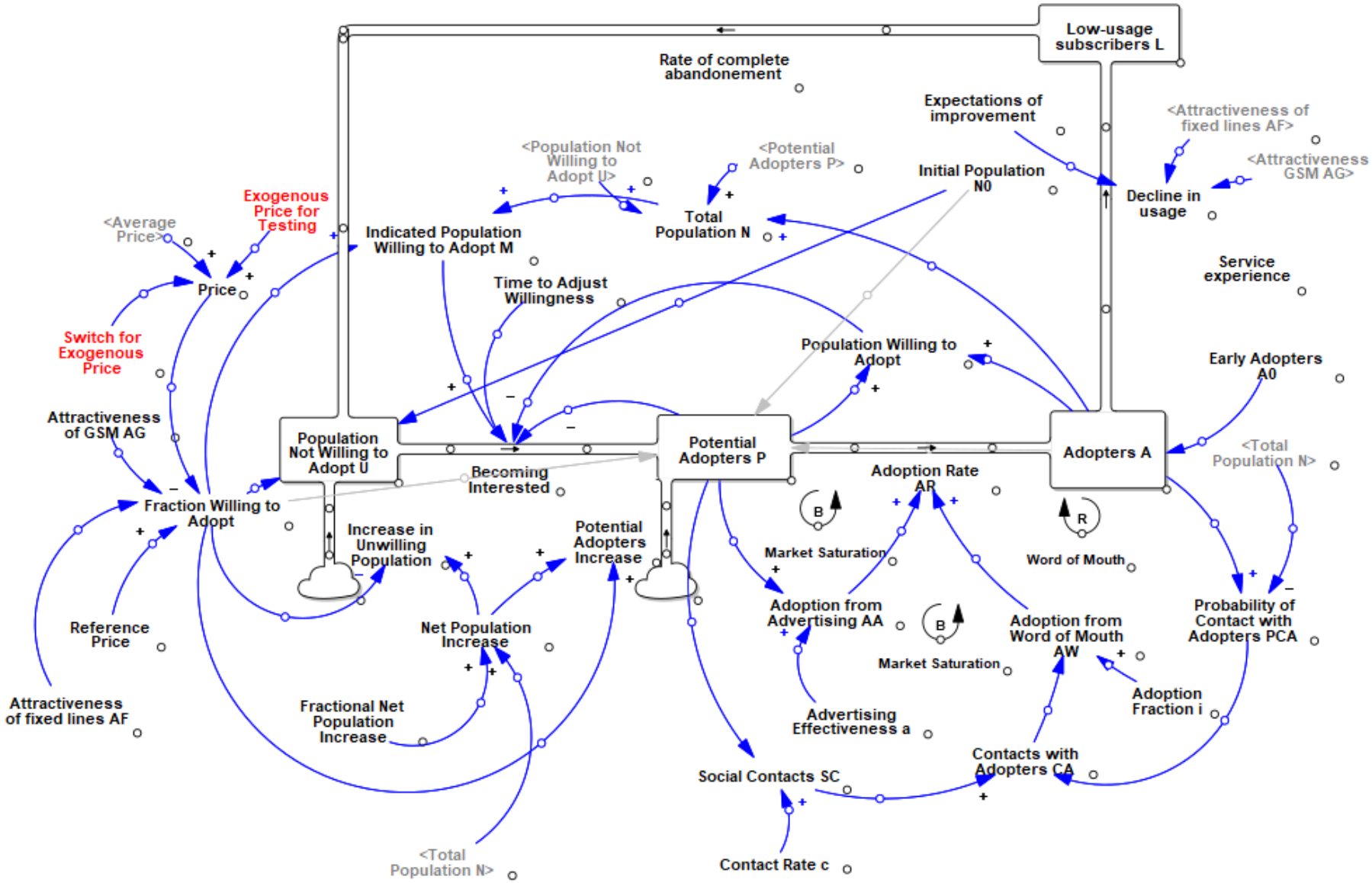
- Modelling of expected diffusion of services
- Carrying capacity qualified by demand

Staggered Licensing

- Licensing contingent to constant measuring of economic viability
- Lack of viability or real demand leads to denial of further licenses

System Dynamics Based Assessment of Diffusion

- Standard & tested Bass Diffusion Model to test demand
- Augment with time-series forecasting for alternatives
- Predict regional demand and carrying capacity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Contact Rate c
<Total Population N>
Adoption Fraction
<Adopters A>

Staggered Licensing Based on Real Options

- Real options-based launch cadence
- Existing work in domain from de Neufville and de Weck
- Launch cadence have to account for failure
- Demand tested at every level

Summary and Aims

- Multitude of problems due to lack of models for small sat. ecosystem:
  - Unfettered, exponential growth of small satellites in low-Earth orbit
  - Unproven business models existing in a vacuum
  - No understanding of orbital commons and impact on stakeholders
  - No understanding of potential collapse and fall-out
- Technology gap in:
  - Combining forecasting with industry model
  - Creating policy informed by comprehensive industry models
- Primary aim: to develop the foundations of a system dynamics-based understanding of small satellite ecosystem
- Use of models in policy creation