AN ECONOMIC VALUATION METHODOLOGY FOR SPACE DEBRIS

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25/10/2017

From Physics to Economics

Economic specification of Earth orbits

- Earth orbits describe a common pool resource:
  - it is non excludable but rival
- It is an ecosystem:
  - its exploitation provides users with peculiar benefits (also called ecosystem services)
- Space debris represent a negative externality to the orbital resource:
  - Producing more pollution reduces the utility provided by the orbit
- Users have preferences for satellites orbital trajectories:
  - e.g. Sun-Synchronous Orbit is prefered for Earth Observation Satellites

Problematic

- Bad resource management:
  - Pollution, scarcity, increase in cost and risk
- Feasible solutions:
  - Mitigation guidelines
  - New designs for spacecrafts
  - Active debris removal
- Due to very high costs, it is mandatory to focus most dangerous debris

What kind of methodology could be carried out to valuate the orbital resource for the purpose of improving its quality and ensure its sustainability?

Are the ranks subject to change with these additional parameters?

A SIMPLE VERSION OF SPACE DEBRIS INDEX

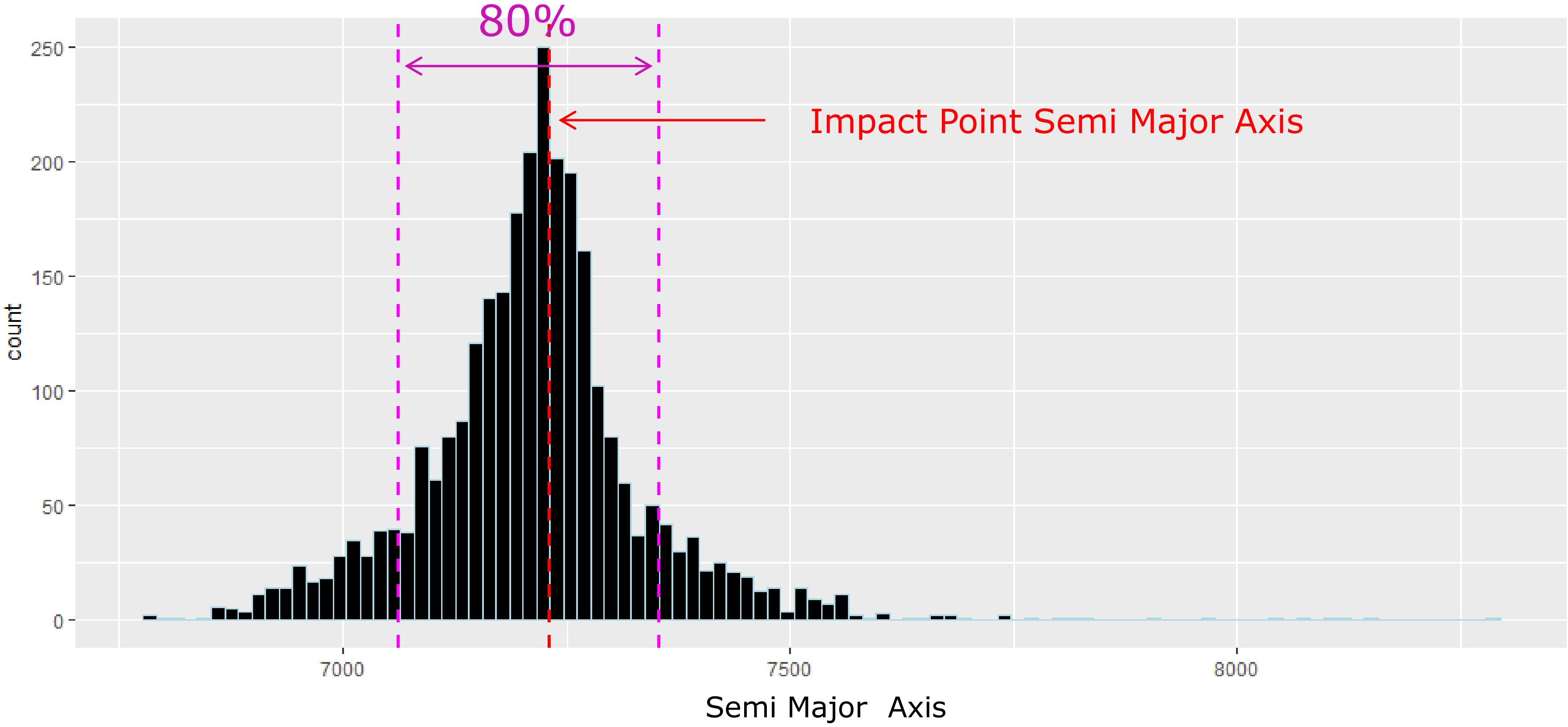
Outline

- Physical Index: $I_{P,M}$
- Value of Space Assets: $Value_j = \alpha S_j + \beta C_j + \gamma \pi_j$
- Economic index: $I^{sat} + I^{deb}$

Current debris classification tools

- NASA debris production function: $N_d = 0,1 \times M^{0,75} \times L^{-1,71}$
  - Derives the number of debris of size above or equal to L
- Collision probability: $P_c(x = n) = \frac{c^n}{n!} e^{-c}$; with $c = vDA_c\Delta_t$
- Debris index: $I_{P.M} = P_c(x \geq 1) \times N_d$
  - i.e. expected number of debris debris of a given size in a given time period
- Missing: post collision environmental consequence, i.e. increased density/flux in the neighborhood of the impact point threatening unequally non and operational objects

State of FY-1C cloud 10 years after

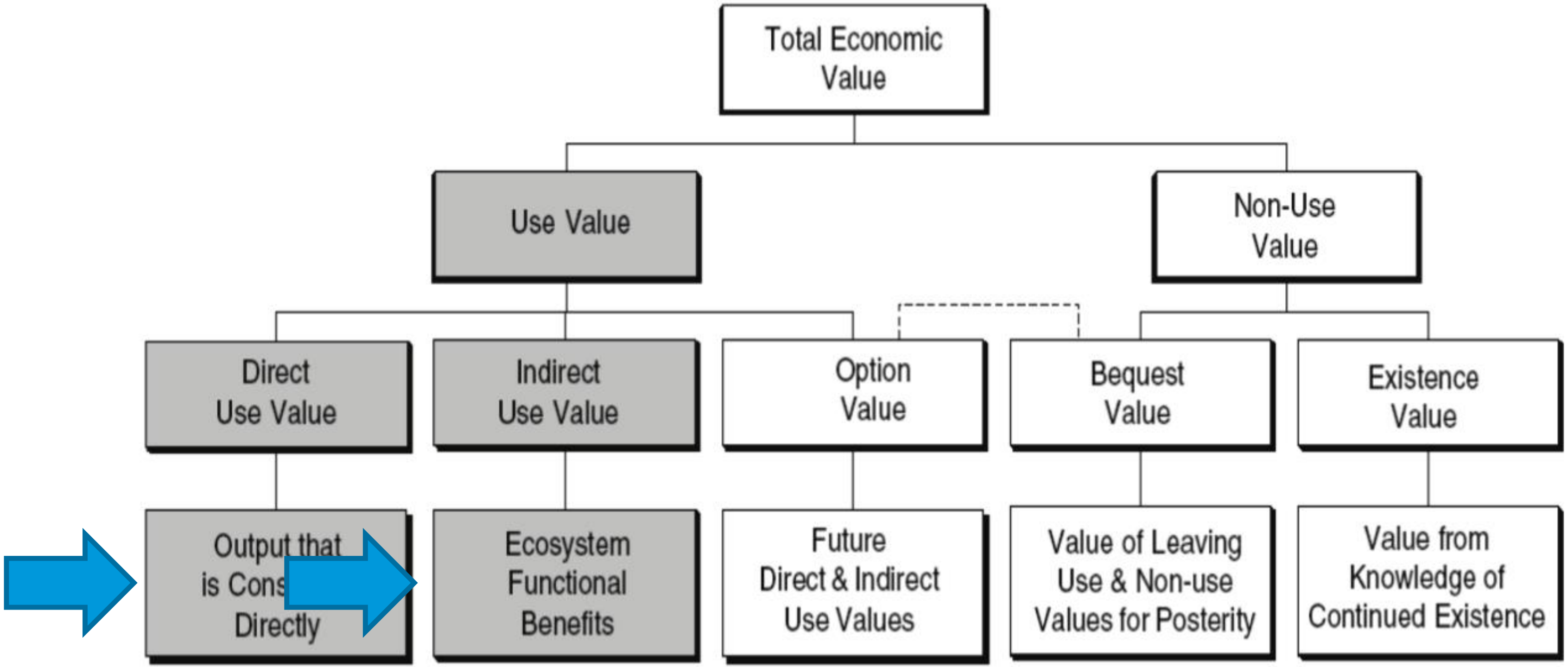


A VALUATION METHOD

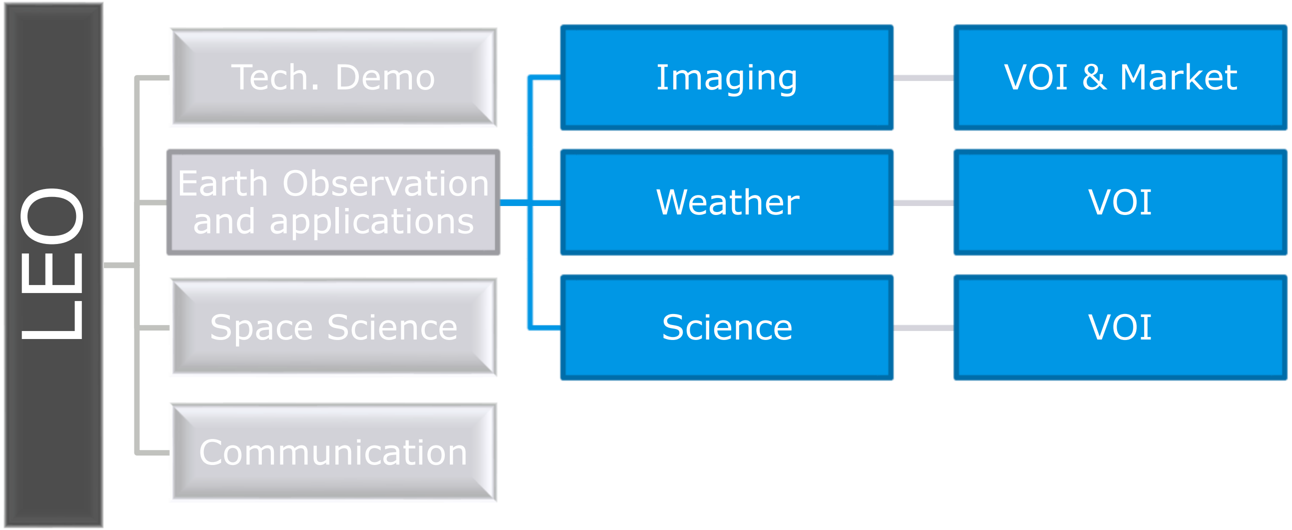
Outline

- Physical Index: $I_{P.M}$
- Value of Space Assets: $Value_j = \alpha S_j + \beta C_j + \gamma \pi_j$
- Economic index: $I^{sat} + I^{deb}$

What determines the value of a resource?



A framework to value Earth orbits



VOI: Value of Information

A framework to value Earth orbits (Earth Observation)

Macauley's value of information determinants (2006):

- Outcome at stake (+) - $\boldsymbol{\pi_j}$
    - Nature of the application: ocean, land, meteo…
- Second Best substitute (-) - $\boldsymbol{S_j}$
    - Tradeoff between quality/quantity and costs from other sources, (in situ measurement, other spacecraft's…)
- Cost of obtaining/processing the data (-) - $\boldsymbol{C_j}$
    - Production, processing, learning, access

$$Value_j = \alpha S_j + \beta C_j + \gamma \pi_j$$

AN ECONOMIC AND ENVIRONMENTAL INDEX

Outline

- Physical Index: $I_{P.M}$
- Value of Space Assets: $Value_j = \alpha S_j + \beta C_j + \gamma \pi_j$
- Economic index: $I^{sat} + I^{deb}$

Neighborhood approach

- The environmental parameter must consider the “precise” location where an eventual break-up would take place

- The additional density will be decreasing with respect to the distance between a debris and the break-up location

- The analysis do not take into account the evolution of a cloud over time. I consider that 80% of the distribution sticks around the impact point for 10 years

Economic and Environmental index

For a given debris, « I^{sat}» is the weighted sum of all the active satellites value present in the ellipsoid of the eventual breakup.

$$I_{\epsilon}^{sat} = \sum_{j \in J} \mathbb{1}_{\epsilon}(sat_j) \times \omega_j(h,i) \times Value_j \qquad (value_j = \alpha S_j + \beta C_j + \pi_j)$$

For a given debris, « I^{deb} » is the weighted sum of all the non-operational objects mass present in the ellipsoid of the eventual breakup.

$$I_{\epsilon}^{deb} = \sum_{k \in K} \mathbb{1}_{\epsilon}(deb_k) \times \omega_k(h,i) \times mass_k$$

Where omega is the distance (weight) function

A new index for space debris

The new index writes:

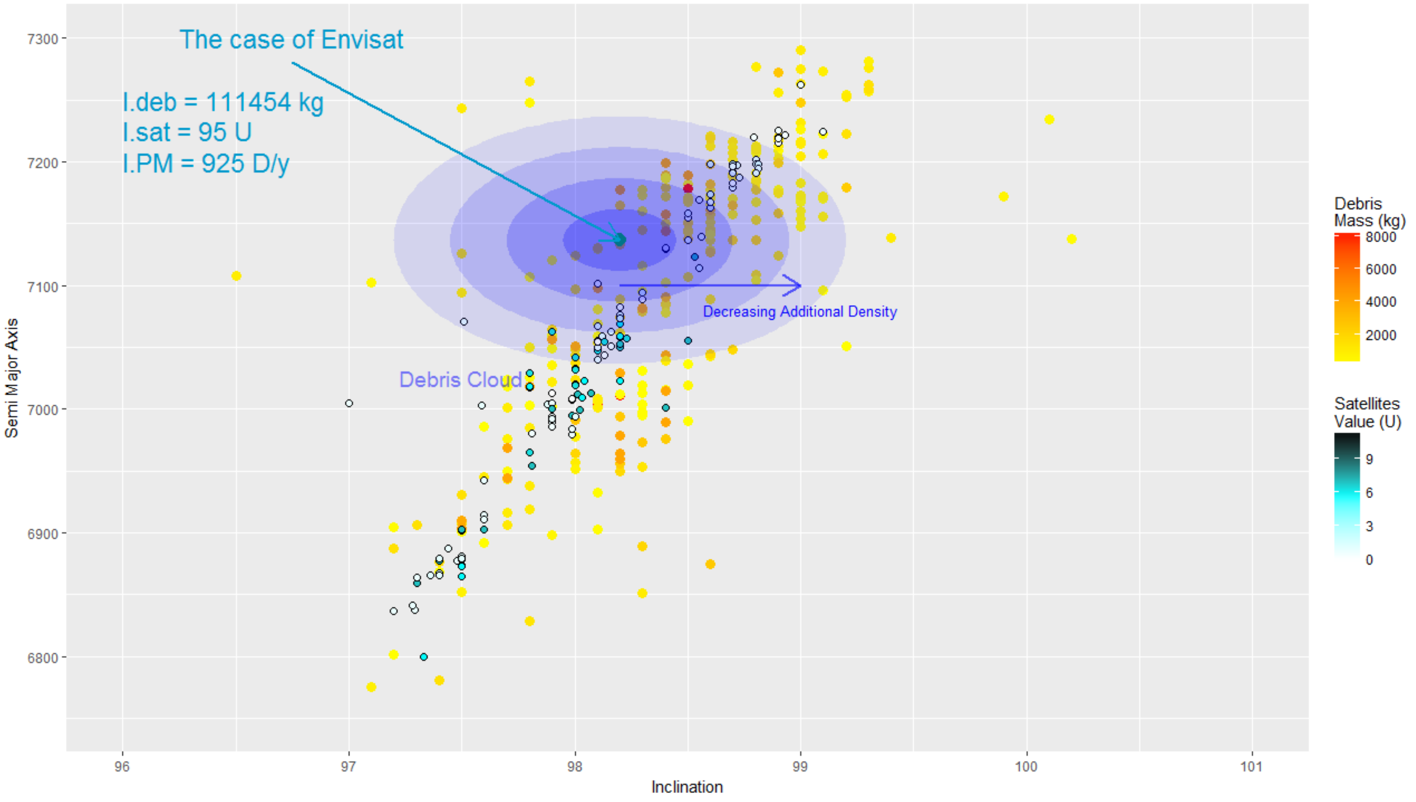
$$I = \left(\frac{I_\epsilon^{deb}}{\bar{I}^{deb}} + x\frac{I_\epsilon^{sat}}{\bar{I}^{sat}}\right) \times \frac{I_{P.M}}{\bar{I}_{P.M}}$$

Where $\bar{I}$ are norms computed with respect to a dummy debris with values set to:

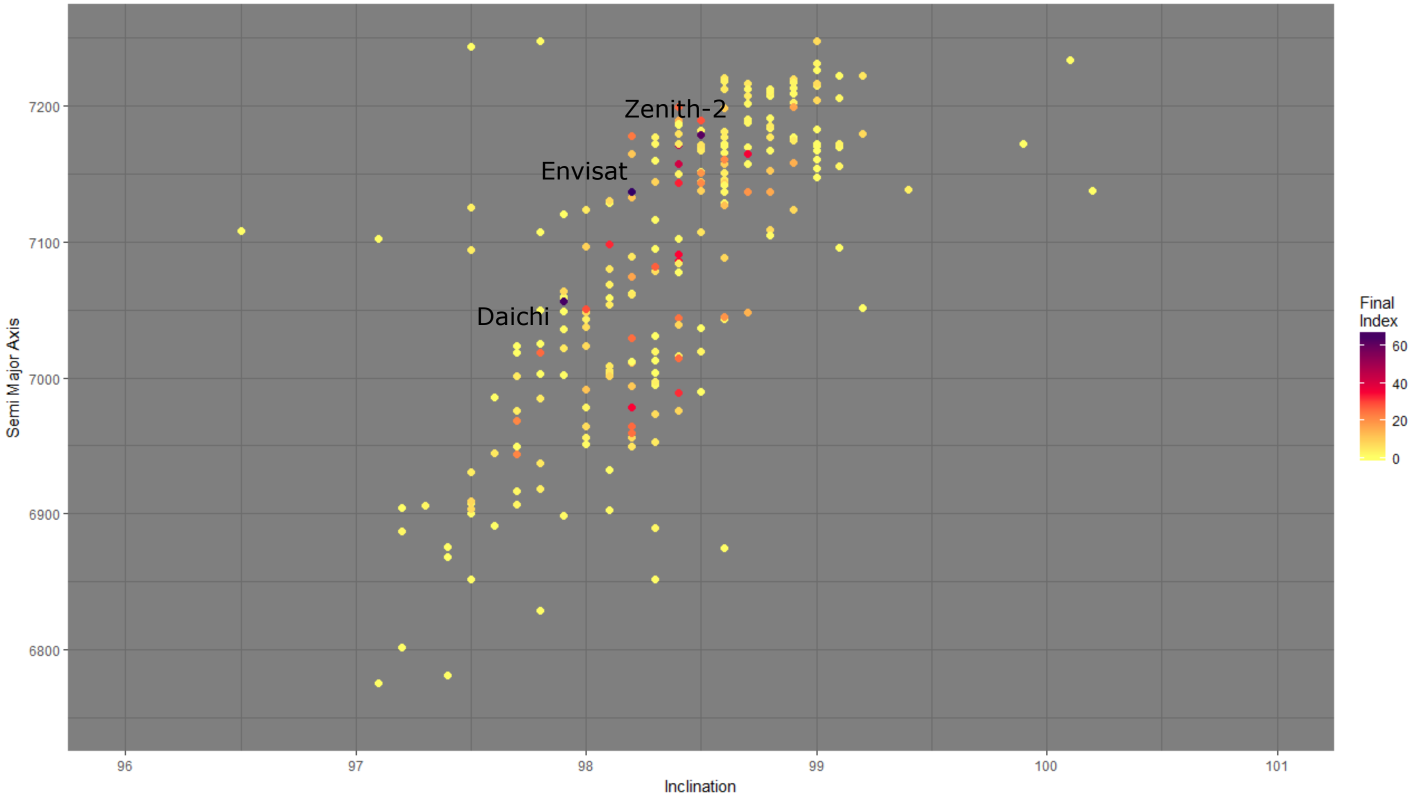
- $SMA_0 = 7171km; i_0 = 98{,}5deg; m_0 = 1031$

Where x is the share of objects smaller than 7cm and bigger than 1cm produced in a breakup event

Illustration



Results: Application to the Sun-Synchronous Orbit



THANK YOU

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Name	I_{PM}	I^{deb}	I^{sat}	I
Envisat	924.67	111454.41	95.40	614.00
Zenit-2 second stage	193.96	107294.30	220.36	255.33
Daichi	197.41	98412.80	217.05	253.89
Zenit-2 second stage	193.66	105886.15	218.48	252.62
H-IIA 202 second stage	107.37	100939.53	195.04	126.03
Ariane 5 second stage (EPS L10)	93.96	111772.92	217.87	123.07
H-IIA 202 second stage	105.34	97332.48	187.44	118.88
SPOT 4	99.43	124592.31	187.46	116.15
CZ-2C second stage (L-55)	81.35	107254.79	229.41	110.96
CZ-2C second stage (L-55)	99.65	118819.56	171.78	107.34
SPOT 5	102.64	126606.23	161.84	106.33
Zenit-2 second stage	302.22	116110.05	33.65	104.38
CZ-2C second stage (L-55)	75.79	102055.84	218.57	98.48
CZ-2C second stage (L-55)	71.15	109466.36	223.51	95.07
CZ-2C second stage (L-55)	76.89	122772.48	197.77	93.80
CZ-2D second stage (L-53)	76.54	104610.50	203.05	93.48
CZ-2C second stage (L-55)	70.61	110088.39	212.54	90.32