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Would the Introduction of a Space Environment Tax Be Effective in Balancing Space Activities and the Space Environment?

宇宙環境税の導入は宇宙活動と宇宙環境の両立に有効か？

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When external diseconomies such as environmental pollution by companies occur, the introduction of an environmental tax is considered as a means of controlling environmental impact while maintaining economic activity. This study focuses on the concept of a space environmental tax as a mechanism to autonomously balance space development activities with space environmental protection. Previous studies have pointed out the positive and negative effects of introducing an environmental tax, and it is thus necessary to assess the systematic and long-term effects of the policy intervention. This study aims to model space activities and the associated increase or decrease in debris as an ecosystem and to examines whether the introduction of a space environmental tax can promote space activities by companies while preserving the space environment. A model was built using system dynamics to reproduce the interaction between spacecraft launches and debris generation, and a 30-year simulation was performed. The results suggest that, by setting an appropriate space environment tax rate, the number of spacecraft and the number of debris could be balanced at a constant level in the long term and sustainable space environment protection could be achieved.

企業等による環境汚染等の外部不経済が発生する場合、経済活動を維持しつつ環境負荷を抑制する手段として、環境税の導入が検討される。本研究は、企業等による宇宙開発活動と宇宙環境保全を自律的に均衡させる仕組みとして「宇宙環境税」の概念に着目する。先行研究では環境税の導入に正負の効果が指摘されており、体系的かつ長期的な影響を評価する必要がある。本研究は、宇宙開発活動とそれに伴うデブリの増減を生態系システムとして捉えてモデル化し、宇宙環境税の導入により、宇宙環境保全を図りつつ、企業による宇宙開発活動を促進させることが可能かを検証する。システム・ダイナミクスを用いて宇宙機の打上とデブリ発生の相互作用を再現したモデルを構築し、30 年間のシミュレーションを実行した。結果、宇宙環境税率を適切に設定することで、宇宙機の数とデブリの数を長期的に一定水準に均衡させ、持続可能な宇宙環境保全を達成できる可能性が示唆された。

Would the introduction of a space environment tax be effective in balancing space activities and the space environment?

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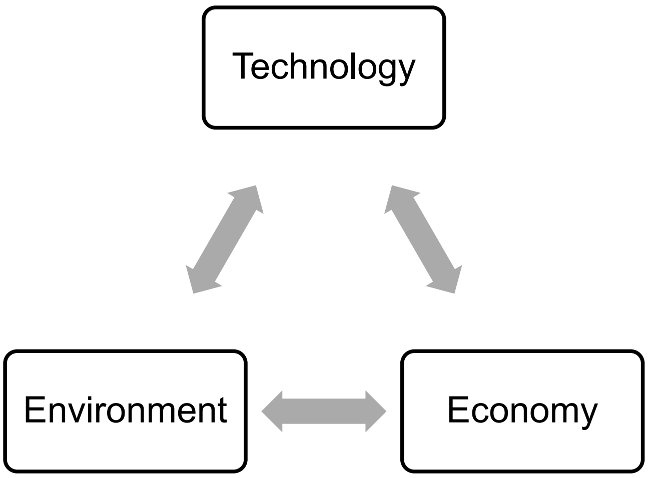
Issue

- **Economic Kesler Syndrome** (Adilova et al, 2020)
  - The phenomenon of increased debris and then the increase of debris collision probability influence the cost of spacecraft development and operation and makes commercial space activities unprofitable.



Purpose

- Adilova et al. (2020) suggest that a high taxation on space debris may reduce the debris generation rate.
  - Pros and Cos of environment taxation
    - Creating financial resources for the environmental protection activities and Inducing voluntary measures by the private companies (Xiao et al., 2021)
    - A high tax rate may inhibit economic activities (Mardones and García, 2020)
- This study aims to examine the concept of a space environmental tax (SET) as a mechanism to autonomously balance space development activities with space environment conservation.

Research Question

Would the introduction of a space environment tax be effective in balancing space activities and the space environment?

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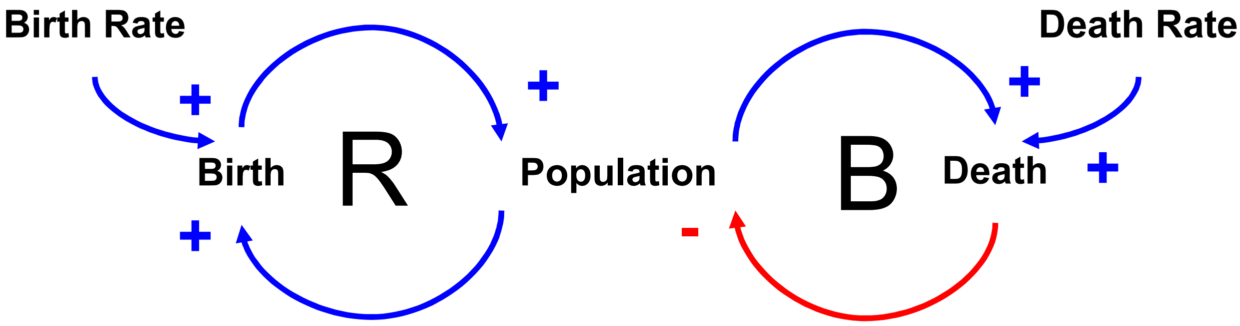
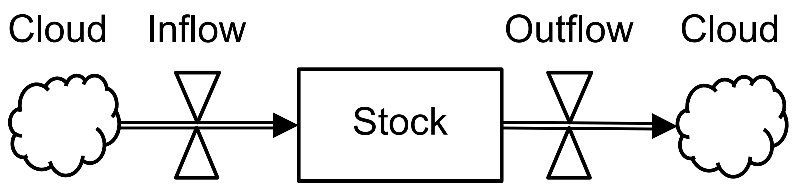
Method

- **System Dynamics** (SD)
  - is a method to simulate the dynamic behavior of a system over time by reproducing the feedbacks among the system elements.[8]
  - causal loop diagram (CLD) is used to identify feedback loops that influence the system behavior.



Method

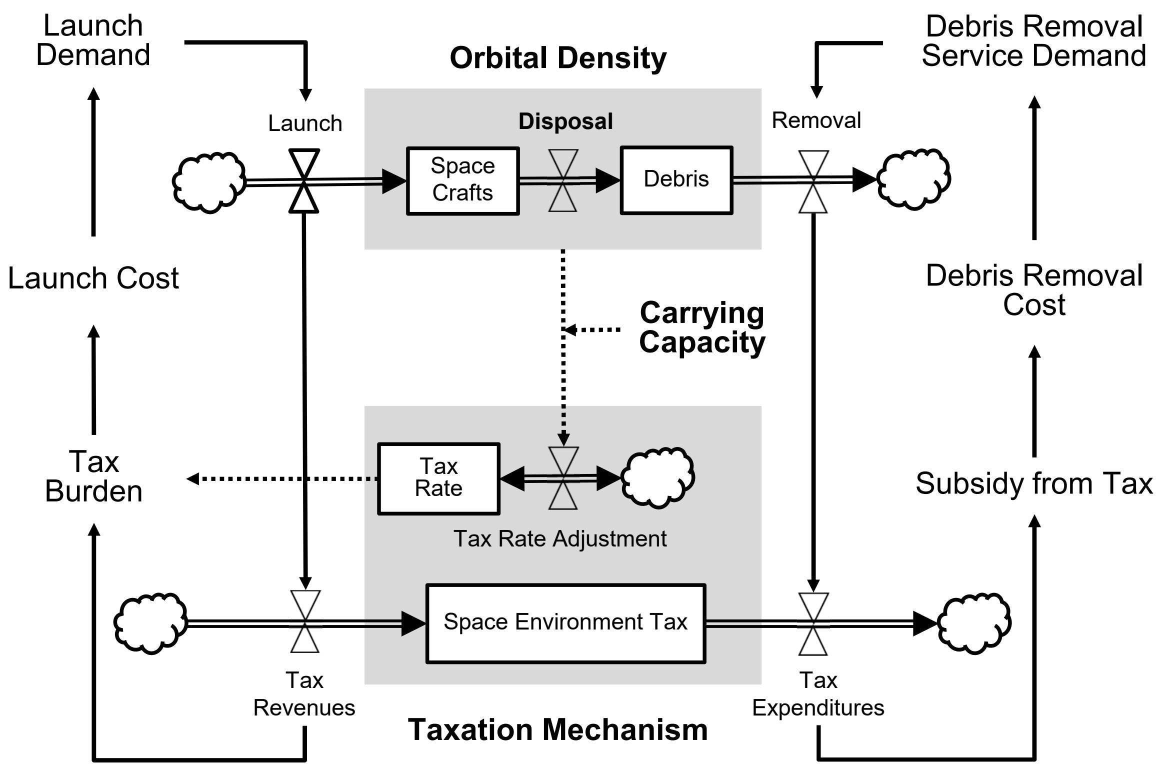
- **Stock Flow Diagram** (SFD)
  - Consists of a stock representing the accumulation of material or information in the system, an inflow into the stock, and an outflow from the stock, clouds are unlimited resource containers.



  - Integral calculation of the difference between the in-flow (t) and out-flow (t) per unit time accumulated in the stock, adding the initial value (t_0) of the stock, and estimating the stock's state at time (T) .

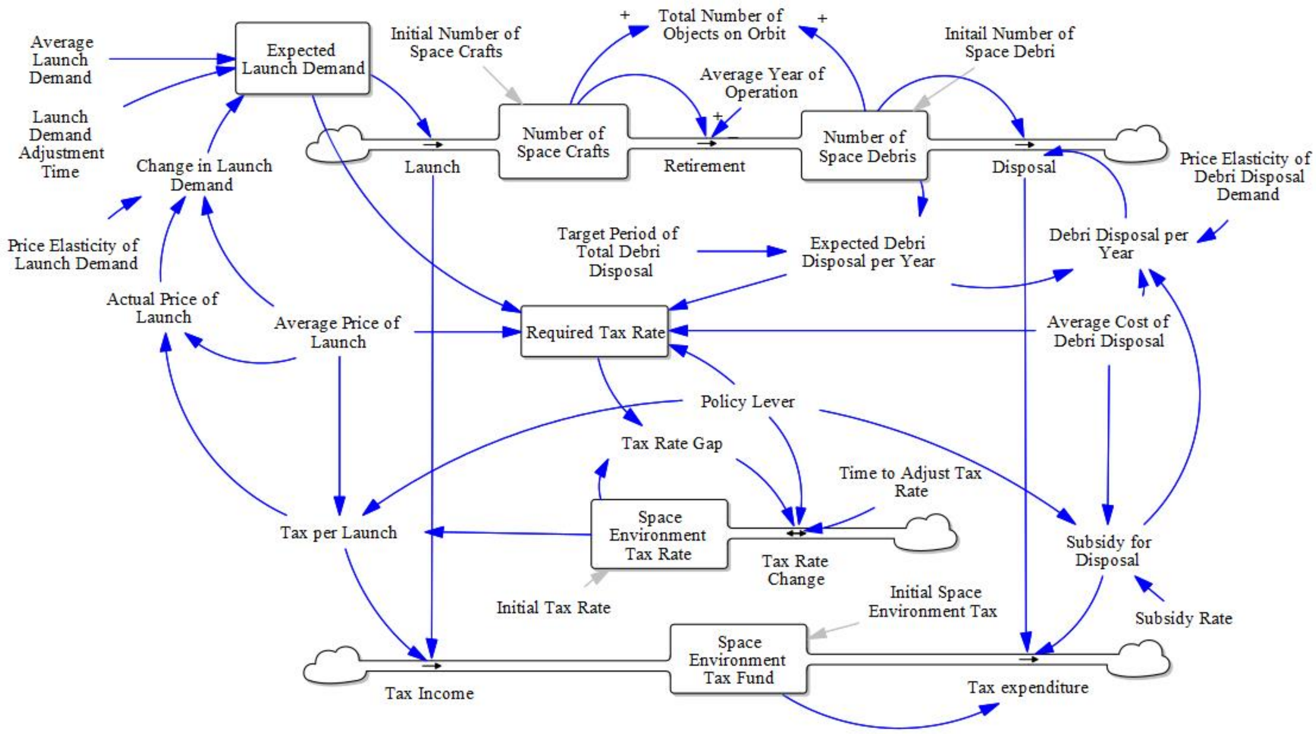
$$Stock(T) = \int_{t_0}^{T} [Inflow(t) - Outflow(t)]dt + Stock(t_0)$$

Model Design



Model Design in Stock and Flow Diagram

Model Building



Space Environment Tax Simulation Model (VENSIM 9)

Simulation

- Simulation Condition
  - Assumed a single orbit
  - Simulations run for 30 years, with 2 scenarios
    (1) “without” SET and (2) “with” the SET
  - SET is paid by the operators according to the launch price and the tax rate varies according to the orbit density.
  - 90% of the debris removal cost is compensated from the SET.

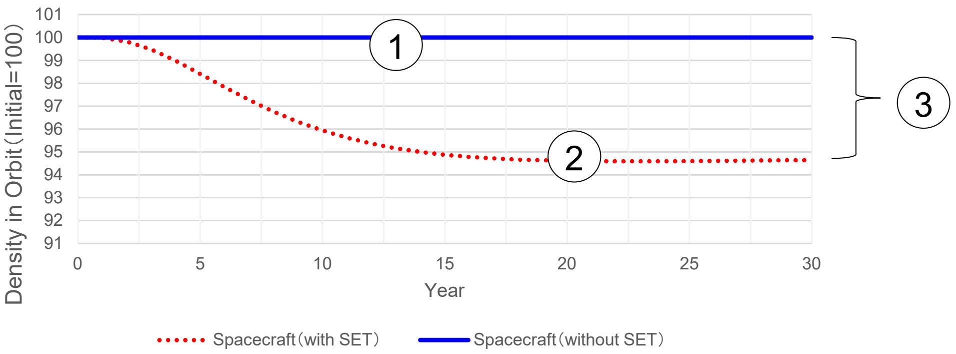
Name of Variable	Value
Initial Number of Space Crafts	100
Initial Number of Space Debris	100
Average Demand of Launch	10/year
Average Years of Operation	10 years
Average Price of Launch	$100 million
Average Price of Debris Disposal	$10 million
Subsidy Rate	0.9
Price Elasticity of Launch Demand	0.9
Price Elasticity of Debris Disposal	0.9

Results (Spacecraft)

① In the scenario without space environment tax, the number of spacecraft is unchanged from 100 because launch demand is assumed to be constant.

② On the other hand, in the scenario with the space environment tax, the tax burden increases the launch price, and the price elasticity reduces the demand for launches, so the observed impact is a decrease in the number of spacecraft.

③ However, the decline rate will be limited to a maximum of 5% and will move toward equilibrium over the long term.



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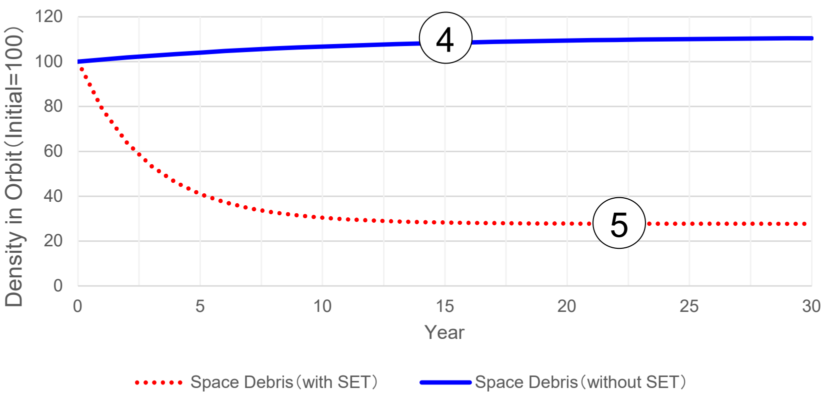
Results (Space Debris)

④ In the scenario without the space environment tax, the number of debris showed a slight increase (solid line: blue)

⑤ In the scenario with the space environment tax, a significant decrease in the number of debris was observed (dotted line: red).

– This is because the tax burden reduced the launch demand and suppressed debris generation, at the same time subsidizing the cost of debris disposal and encouraging operators to promote the disposal.



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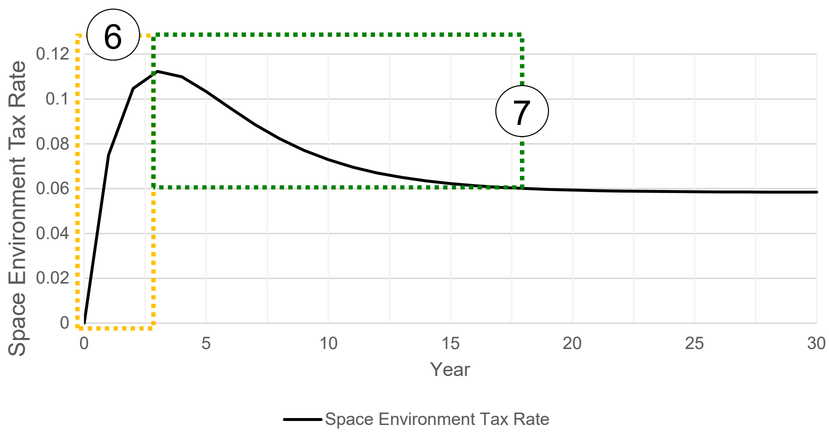
Discussions

- The space environmental tax rate changed adaptively in response to orbital space density, possibly moderating the overall impact.
  - Initially, the space environmental tax rate increases due to the high spatial density (⑥), which suppresses the increase in debris, and then the space environmental tax rate decreases toward equilibrium with the debris processing capacity (⑦).
  - Suggests that the optimal design of the taxation mechanism may keep the economic impact within a certain range



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Summary

- Summary
  - A 30-year simulation was performed using system dynamics to examine the interactive behaviors between spacecraft launches and debris generation.
  - Concluded that introduction of the SET would enable the maintenance of a certain level of space density in orbit by adoptively changing the tax rate.

- Future works
  1. Model validation based on space debris database
  2. Risk evaluation model on debris collision
  3. Legal issues on the taxation right on space debris

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