

**Debris or Not Debris:  
What Should Policy Makers Do About Trash Accumulating in Outer Space?**

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Resources for the Future

April 2009

**Abstract**

The number of active spacecraft orbiting the earth for weather, climate, and environmental monitoring, telecommunications, global positioning systems, and other purposes has increased steadily since the dawn of the space age in 1957. Use of space has led to an accumulating amount of debris orbiting the earth including defunct satellites and rocket bodies; mission-related debris like discarded camera lens caps, stray nuts and bolts, paint chips, and (frozen hard) particulates from propellant fuel; and fragmentation debris due to a cascading effect as orbiting debris collides with itself and breaks into smaller projectiles. Most debris is located at altitudes where space activities currently take place and debris accumulations are largely irreversible.

China's recent destruction of a defunct weather satellite heightened growing concerns about the collision risk to active spacecraft posed by orbiting debris traveling at tremendous speeds. On present trends, some analysts believe that many low-altitude orbits will become unusable within two decades. Others argue that the problem is manageable through various, albeit costly, strategies to mitigate debris generation and/or adapt to collision risk. One strategy is to incorporate orbital maneuvering capability into spacecraft (e.g., through additional fuel reserves) which can help them to avoid observable projectiles (but not small projectiles). Similar capacity can also be used for safe retirement of defunct space vehicles to a "graveyard" orbit. And space vehicles can be designed to contain debris generation, for example by using thicker or stronger craft materials (which also reduces own-damage risk), tethering of disposable parts like nuts and bolts that would otherwise escape during rocket separation, and incorporating capability to combust residual rocket fuel.

Nonetheless, space vehicle producers and operators currently under-invest in these strategies, to the extent they would yield spillover benefits to other operators through reduced

collision risk. This suggests the Pigouvian prescription of pricing both launch rockets and spacecraft to account for their impact on elevating collision risks for (current and future) space fleets. In fact, a system of launch taxes, with various rebates, can be designed to mimic outcomes under first-best pricing. It would be feasible to provide rebates, at the end of a craft's useful life, following successful use of orbital maneuvering capability and for graveyarding of the craft. It is also feasible to design a system for ex ante rebates based on debris containment technologies incorporated in spacecraft and rocket manufacture.

This paper provides a first attempt to model and quantify the magnitude of space debris externalities, the optimal tax system for addressing them, and whether there are quantitatively important differences in efficiency between the first-best and a range of alternative second-best tax structures. To do this, we derive intuitive and empirically useful formulas for the optimal tax structure using an analytical model of externalities of large (observable) and small (unobservable) debris generation that encompasses all the mitigation/adaptation strategies just described as well as debris cascading. We then apply the analysis to representative spacecraft types (varying by cross-sectional surface area) that are either deployed to relatively crowded or relatively uncrowded orbits, based on both a current baseline scenario and on a business-as-usual projection for 2030. This involves an extensive estimation of parameter values obtained from synthesizing projections from debris generation models, projections of spacecraft fleets, engineering analyses of mitigation/adaptation technologies, and of productivity losses from debris collisions.