INVESTIGATING SOCIAL DIVIDES IN WASTE REDUCTION POLICY: HOW CONGESTION PRICING CAN INFLUENCE SPACE DEBRIS MITIGATION

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By

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Greenhouse gas emissions and space mission fragments are examples of waste that have detrimental effects on the environment, economy, and health of both a locality and the global population. The students of the spacecraft design capstone course, advised by Christopher Goyne at the University of Virginia Department of Mechanical and Aerospace Engineering, aim to collect road-based weather information via a constellation of satellites. Delivering this data to roadway users, roadway managers, and first responders will reduce weather-related traffic congestion. Our spacecraft cannot meet its potential without complementary legislation addressing the key issue. Additionally, the ever-increasing threat of space debris greatly effects the technical development of this project. Yet space debris social policy development is behind compared to traffic congestion policies. Therefore, the STS research paper will explore how known social impacts of traffic congestion policies can influence the examination of similar policies to clean up space debris. Using the Social Construction of Technology framework (Pinch & Bjiker, 1984, p. 410). The technical and STS theses are tightly coupled since improvements to waste reduction policy bolsters the use of innovative technologies.

Reducing waste is a worthy cause both on roadways and in outer-space orbits, but technology alone cannot solve these problems. A summary of the lessons learned stems from an analysis of the social groups affected by traffic congestion policies. Then the relationship between vulnerable and privileged social groups in outer space affairs contextualizes the need for policy. From there, conclusions arise regarding the applications and limitations of traffic congestion policy to emerging space debris policy. Above all, it is important to ensure waste mitigation policies do not unintentionally further social divides.

STUCK IN A JAM: INTANGIBLE WASTE FROM CROWDED ROADS AND ORBITS

Traffic congestion is more than an inconvenience. Statewide, TRIP (2020) reported poor road conditions cost Virginians $9.5 billion each year. Congestion comprises nearly half of these losses (p. 1). Crowded roads are not only economically disadvantageous, but they also cause fatalities. Between 2014 and 2018, an average of 775 people lost their lives yearly on Virginia roads (TRIP, 2020, p. 9).

Risks to human health and safety on the road extend beyond traffic accidents. As Lindsey and Santos (2020) point out, 20% of global carbon dioxide emissions come from vehicles, so society cannot ignore that pollution from traffic congestion is somewhat responsible for many of the health issues associated with climate change (p. 1). For instance, inhaling hazardous chemicals from air pollution in London in 2016 was 10 times more fatal than traffic accidents (Braizer, 2016, para. 4). Curbing traffic congestion is a worthy cause for many reasons: saving drivers' money, reducing fatalities, and lowering emissions.

While roads overflow with vehicles, Low Earth Orbit (LEO) is likewise inundated with space debris. As of 2018, LEO is home to nearly 16,000 objects (Witze, 2018, Figure 2, "Busy Skies"). But above all, inactive satellites and fragments make up around 95% of orbits (Witze, 2018, "The Orbiting Dead"). Space debris is not only a global problem; the issue has a profound effect on the average person's way of life. When more collisions occur and create more space junk, operators may choose pricier, unideal orbits. These decisions increase the cost or decrease the quality of services satellites provide. Also, missions designed to improve mapping, communication, or infrastructure may not make it to orbit if debris persists (European Space Agency, 2020, n.p.). Additionally, satellites are useful tools for scientific research on many

societal problems, including climate change. Delays in these missions would undoubtedly affect the well-being of a locality.

EFFECTIVELY USING SOCIAL POLICY TO REDUCE WASTE

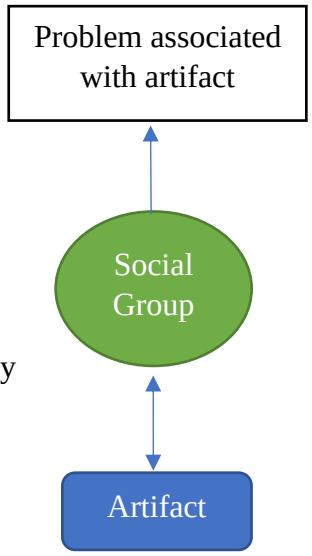

Figure 1: Social Construction of Technology Concept Map Legend. This figure establishes the mapping format implemented throughout the rest of the paper. (Adapted by Raeann Giannattasio (2020c) from W.B. Carlson 2007).

A case study of two social policies under consideration to limit traffic congestion and space debris, respectively, will ensue using the Social Construction of Technology (SCOT) framework. In this paper, waste reduction social policy includes any legislation, both domestic and international, conducive to human welfare. According to Johnson (2005), Pinch & Bjiker (1984) developed the SCOT method as a rejection of technological determinism (p. 1792; p. 411). Figure 1 on the left is a concept map legend that helps visualize the application of SCOT. Instead of viewing technological development as a process closed off to the outside world, Pinch & Bjiker (1984) recognized that a variety of social factors influence a technological artifact (p. 423). With this framework, we consider innovation as a two-way street. The double arrows in Figure 1 indicate that the artifact and social group influence one another. Technology shapes society upon implementation, but society also changes the technology. User interpretation of a technology affects its success, where users of a technology with a shared interpretation are defined as a social group. When social groups have differing perceptions of the artifact, this is called interpretive flexibility. Tracking all the social groups, their problems with a technology, and the resulting technical iterations is the SCOT method in practice.

Social policies are considered the artifact in this SCOT analysis. One policy is congestion pricing, also called road pricing, where cars pay a fee to enter a busy area during peak hours. The funds generated promote efforts to switch away from fuel-burning vehicles (Tirone, 2020, para. 2). The other policy, Orbital Use Fees (OUFs), addresses the space debris issue by putting a price on orbits themselves (Rao, Burgess, & Kaffine, 2020, p. 12756). Researching the two in tandem reveals how lessons learned from traffic congestion social policy can help declutter LEO.

A SCOT analysis can identify populations these policies neglect. Recognizing inequity in the policies helps steer implementation and regulation in a direction that will alleviate these burdens. In this way, the perspectives of the social groups further refine the artifact.

PUT A ROCKET UNDER TRAFFIC CONGESTION POLICY LESSONS LEARNED

As stated earlier, technology alone cannot resolve either traffic congestion or space debris. Both environmental issues will only get worse without immediate legislative action. Despite the varied success of attempts to implement social policy to reduce intangible waste, the potential of such policies remains clear. Non-technical solutions to address traffic congestion and space debris need to consider the relevant social groups to ensure no one is unintentionally disadvantaged.

Scholars have debated whether congestion pricing bolsters or minimizes social justice since before the policy was implemented in the real world. Congestion pricing promotes social justice if the benefits outweigh the consequences for all social groups in society. Foster (1972) published a paper in the *International Journal of Transport Economics* claiming that road pricing benefits low-income residents (p. 135). In response, Richardson (1974) expanded upon the social complexities surrounding congestion pricing (p. 83). Their conflicting papers offer differing perspectives on the relationship between congestion pricing and social justice. In the time since

their written deliberations occurred, many cities all over the world have instituted this economic model. Present-day case studies can either confirm or deny the two authors' claims.

In contrast to the vast amount of literature on congestion pricing, social policy designed to mitigate space debris is sparse. Due to the newness of OUFs, evaluating their social good is incomplete. Not to mention, the United Nations has not revisited global space policy since the 1960s, which makes the Outer Space Treaty (OST) difficult to apply to our space economy today (Grzelka & Wagner, 2020, p. 321). Therefore, this paper serves to investigate the possibility for space debris policy to borrow lessons learned from traffic congestion to create policies that are not only effective but also socially just. Understanding society's current perspective on these two waste issues could provide recommendations for how to adjust developing policies based on past mistakes curbing intangible waste. This is important because neglecting to enact effective policy that will lessen effects of excessive waste threatens our way of life as we know it.

NAVIGATING CONGESTION PRICING: ARE WE MISSING A STOP?

Currently, five cities use congestion pricing to address their crowded roadways: Singapore, London, Stockholm, Milan, and Gothenburg (Linsey & Santos, 2020, p. 4). After one year of fees to enter 8 square miles of London, congestion reduced by 30% and pollution by 25% (Tirone, 2020, para. 3). This is different from other tolls where most of the money collected is for local road fixes (Lindsey & Santos, 2020, p. 4). And yet, this policy has the potential to hinder many social groups. Such groups include, but are not limited to, the low-income homes, non-drivers, and the middle class as rendered in Figure 2 on page 6.

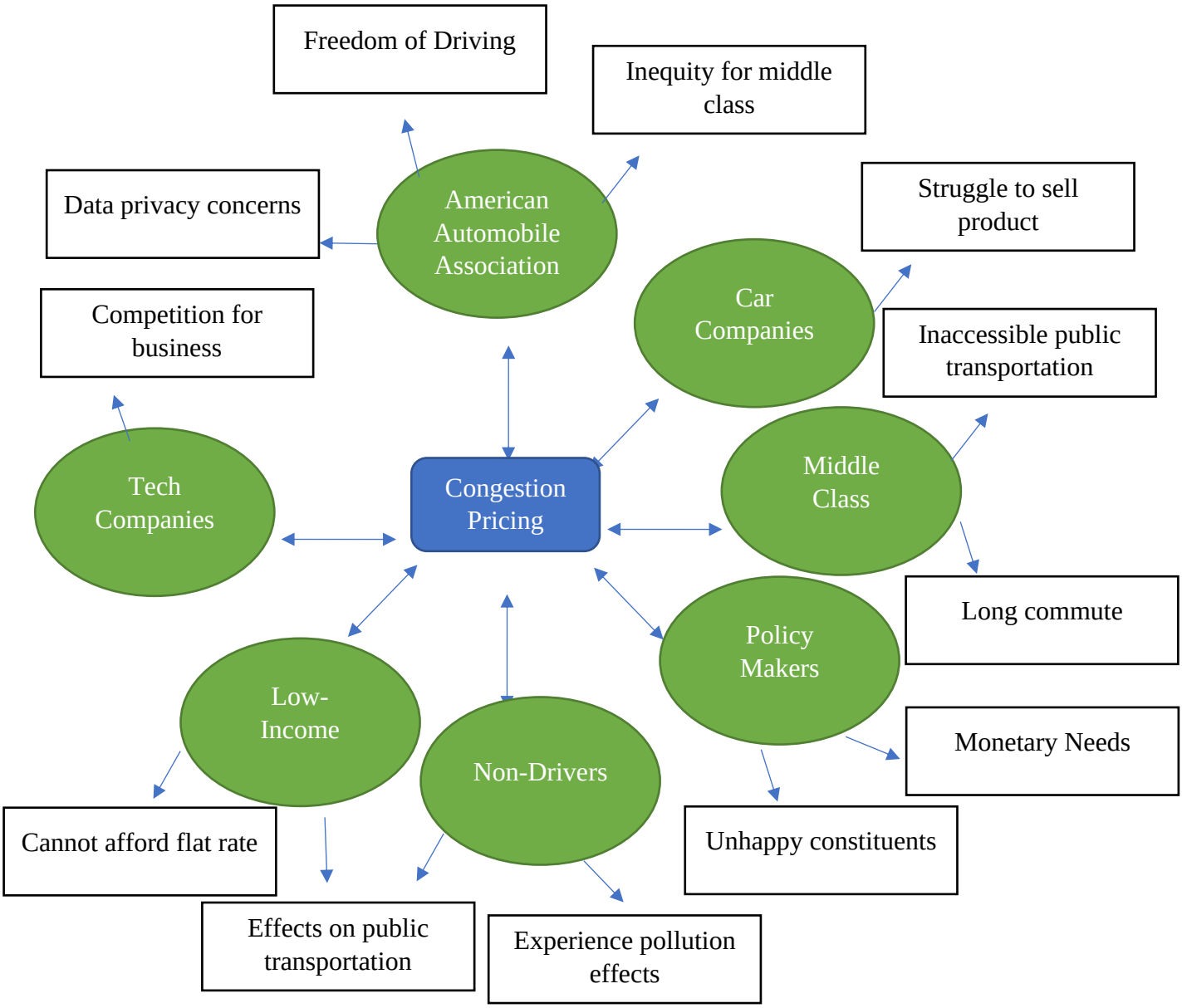

Figure 2: Social Construction of Congestion Pricing. This concept map depicts the different social groups, in green, affected by the artifact, congestion pricing, in blue. Each group's perceptions of the issue are documented in white squares. (Adapted by Raeann Giannattasio (2020a) from W.B. Carlson 2007).

The Highly Contested: Low-Income and Non-Drivers

Upon its introduction, driving was associated with leisure. The wealthy would take their cars out to summer homes for an enjoyable day. In fact, certain roads were constructed, most famously in Long Island, to limit public transit access, keeping the lower class out (Winner, 1986, p. 23). Today, those below the poverty line that own cars are largely using them for necessities such as work and groceries, which contributes to their income bracket driving 20% fewer miles a year than the national average (Manville & Goldman, 2018, pp. 329-330). There are also those that cannot afford a car or simply do not have one. Scholars fervently debate the overall effect congestion pricing has on the quality of life for these social groups, drawing upon aspects such as public transportation, reduction in emissions, and affordability of the tax.

Some researchers argue that the improvements in public transportation outweigh any barriers placed on roads by congestion pricing. With only a small percentage of drivers in the low-income group, it seems justifiable to inconvenience a few to benefit the group as a whole. This utilitarian approach relies on both allocating an appropriate amount of revenue to public transportation and a large enough reduction in traffic so that public transportation will become faster than before. While improvements in speed are likely to occur, it is important to remember that time savings are worth more to the wealthy (Manville & Goldman, 2018, p. 331; Richardson, 1974, p. 83). Extra time is inconsequential when struggling to feed the family or heat the home.

Furthermore, the reductions in emissions associated with congestion pricing are hard to ignore. Areas closer in proximity to the initial source of the pollution benefit the most from these improvements. Manville and Goldman (2018) emphasized that residences near freeways contain higher poverty rates, more non-white people, and older houses (pp. 335-336). Therefore, many living in these areas are likely low-income, non-drivers, or both. Improvements to the health of

these social groups are considerable due to difficult access to proper health care for those in poverty. Importantly, lowering vehicle emissions also helps those that are not paying congestion pricing fees. These residual benefits serve to improve part of the quality of life for vulnerable populations.

Of course, inability to afford the flat-rate at congestion pricing tolls is the most obvious objection to the policy. Cain and Jones (2008) performed a study investigating the effects of introducing congestion pricing in Edinburgh. They found that without congestion pricing enacted, low-income drivers incur motor costs in higher proportion to their income than any other wealth bracket (p. 50). Once again, many low-income drivers own cars out of necessity and are driving to work at peak traffic times. We have all experienced the stress of unreliable transportation to a commitment due to car trouble, a family mix-up, or another impediment. For certain homes, the risks associated with uncertain transportation to work make the increased financial strain acceptable. However, paying a £2 congestion pricing charge weekly would significantly increase hardship for just under two-thirds of Edinburgh low-income drivers (p. 52). This fee appears nominal but greatly affects this social group's quality of life. Any potential benefits must be appropriately compared to the harsh reality of how unaffordable this fee is for many.

The Freedom Fighters: Middle-Class and American Automobile Association

While low-income and non-driver social groups see barriers to driving, others focus on the personal freedom associated with driving. The American Automobile Association (AAA) wishes to preserve the carefree image of driving and feels congestion pricing threatens social justice on the road (Tirone, 2020, para. 6). They largely advocate for the middle-class, who the AAA deems most vulnerable to hardship from congestion pricing.

The key factor inhibiting middle-class drivers is that many of them live in the suburbs, and therefore lack access to public transportation. In addition, many middle-class drivers earn below-average income compared to all drivers, since many people in the low-income bracket do not own a car (Richardson, 1974, p. 82). Since commuting into cities for work via car is common practice for this group, the middle class frequently pays congestion pricing fees during peak times (Tirone, 2020, para. 6). Unsurprisingly, Cain and Jones (2008) discovered that as one gets farther from Edinburgh, the threshold for acceptable payment frequency decreases (p. 50). These added burdens could push middle-class drivers to start carpooling more, which cuts down both personal costs and emissions. However, evaluating such economic and environmental benefits must occur within the overall context of quality of life for this group.

When considering congestion pricing, another concern for drivers is their right to privacy. Most tolls read license plates to charge drivers (Tirone, 2020, para. 4). The AAA advocates for more transparency on the nature of this data collection. As technology integration grows within our society, social groups are privier to the risks associated with gathering personal information. While low-income drivers may also worry about data privacy, concerns for financial hardship threatening their basic needs overwhelm all other apprehensions. Moreover, AAA's role is to advocate for these social justice concerns on all drivers' behalf.

The Policymakers

Since roads reside under both federal, state, and municipal governance, identifying the responsible party is the first step to enacting congestion pricing. No matter who has jurisdiction, it can often be difficult for this social group to vote in favor of any policy that tries to curb hazardous activity. For example, Lindsey and Santos use the term Pigouvian tax to describe this type of social policy (2020, p. 2).

Often, constituents view these policies as restricting their personal freedoms. On the other hand, the generated revenue is a huge motivating factor for approval. After initial inactivity, using accumulated money correctly can make constituents happy enough to continue paying the fee. Policymakers evaluate the benefits of social policy with the drawbacks of worsened approval ratings. Most importantly, subject matter experts need to ensure that policymakers wholly understand the complex social policies. Lindsey and Santos (2020) state that congestion pricing is often undervalued because many policymakers do not understand the full extent of traffic congestion's effect on climate change (p. 10). If many continue to believe that traffic congestion is only a local problem without global consequences, social policy will not effectively mitigate vehicle emissions.

LESSONS LEARNED FROM CONGESTION PRICING

After consulting different studies and analyzing the values of the most relevant social groups, key takeaways from efforts to make congestion pricing a socially just policy can serve as a guide for similar policies in other domains. First, there are long-held beliefs about the freedom of driving that make congestion pricing controversial. Each social group has a different perspective on the historical nature of driving; this viewpoint depends on whether the group was denied access to roads or encouraged to use them for leisure. Second, congestion pricing is far more complex than a preliminary assessment indicates. The improvements in traffic congestion appear to only help drivers through faster commute times. In reality, reductions in vehicle emissions help improve the health and environment for people of varied socio-economic status. Third, funneling generated revenue back into vulnerable populations could improve the social good of this policy. If enough funds go toward public transportation improvements, fee waivers

for burdened drivers, or improvements in housing near high pollution areas, then policymakers and constituents are more likely to be comfortable endorsing the policy.

ORBITAL USE FEES (OUFS): A COVER CHARGE FOR SPACE

Unlike congestion pricing, Orbital Use Fees (OUFs) are a new concept, so there is no current implementation. Despite this, the economic benefits resulting from a study performed by Rao et. al (2020) are hard to ignore. Compared to Business as Usual (BAU) simulations, OUF models show a potential increase in industry value from $600B to $3T. In 95% of randomly drawn results, satellite industry value under OUF simulations was over four times greater than BAU by 2040 (p. 12757). These staggering numbers simulate starting OUF regulation in 2020. Expectedly, the benefits of OUF diminish as the period of latency increases; inaction until 2025 costs the industry $300B. (Rao et. al, 2020, p. 12757). To enact such a policy, the most important consideration is proper regulation. International regulators must maintain orbit pricing, since space is a shared resource. For example, treaties from the United Nations Office of Outer Space Affairs (n.d.), such as the Outer Space Treaty (OST) could include this policy ("Treaties and Principals," n.p.).

However, pricing space in an orbit may harm certain social groups more than others. These social groups and their perspectives on this policy are mapped out in Figure 3 on page 12.

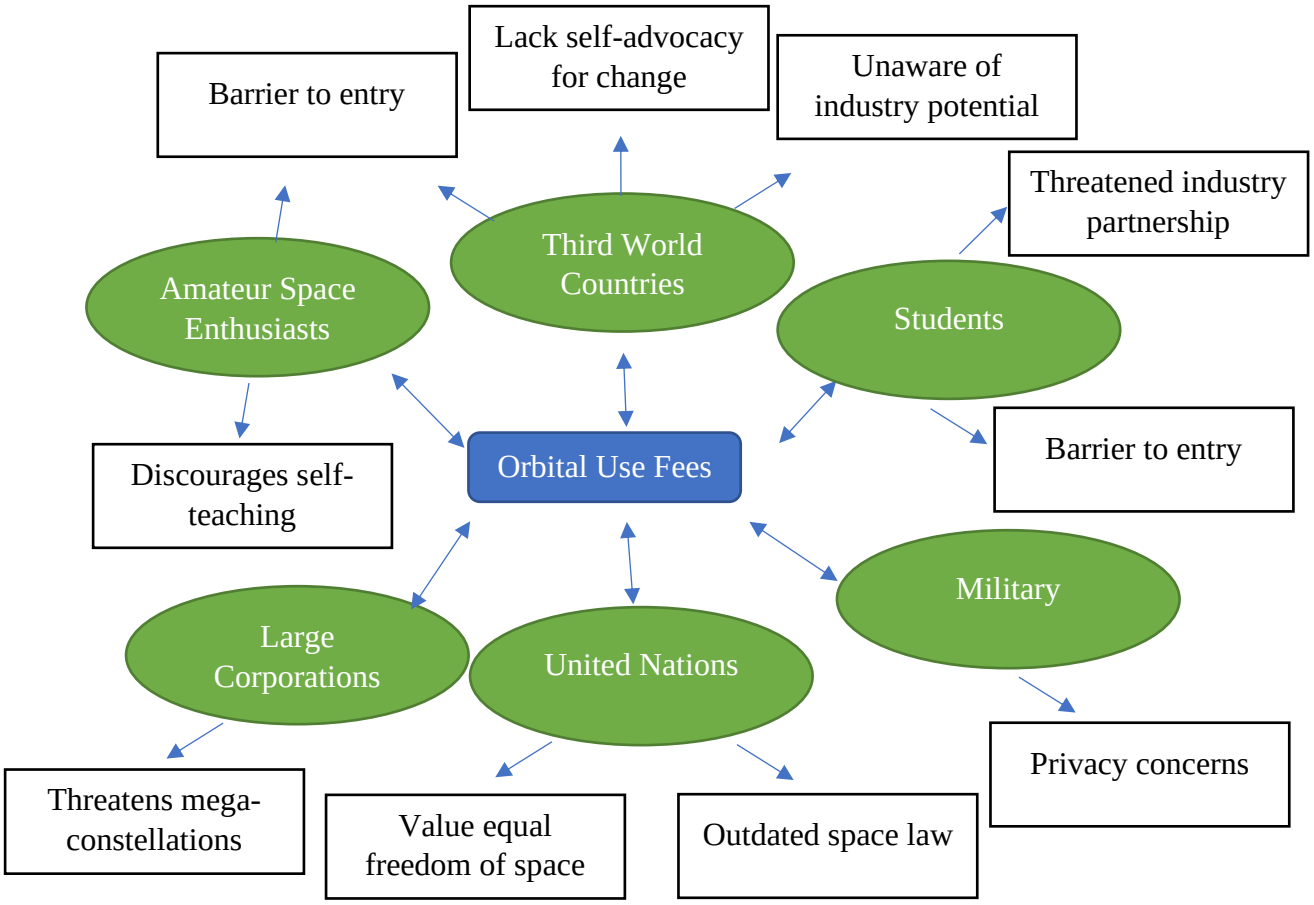

Figure 3: Social Construction of Orbital Use Fees. This concept map depicts the different social groups, in green, affected by the artifact, Orbital Use Fees, in blue. Each group's perceptions of the issue are documented in white squares. (Adapted by Raeann Giannattasio (2020b) from W.B. Carlson 2007).

They Come in Peace: Third World Countries, Students, Amateur Enthusiasts

The three social groups included in this section, third world countries, students, and amateur space enthusiasts, place great value on the precedent set to promote freedom of space. The OST states that space activities should benefit all countries regardless of socioeconomic status (Aganaba-Jeanty, 2016, p. 2). Since the OST's inception in 1967, interactions within space have changed dramatically (Grzelka & Wagner, 2019, p. 321). The three groups listed prior have motivations that differ from typical national powerhouses with historied space programs, but accumulation of space debris and militarization of space threaten those desires.

For developing countries, space is an opportunity to show they bring something of value to the world. Investing in science and technology is a way to increase a nation's presence in the global economy. Paikowsky and Ben-Israel (2011) use the decades-long outer space partnership between India and Israel as a case study to determine how a united coalition in space can best help underrepresented countries (p. 397). India has a far lower Gross Domestic Product (GDP) than Israel but both are historically third world and currently developing countries (p. 395). These nations simply do not have the same massive budget for space as countries like the U.S. and China.

Because of this, third world and developing countries face greater difficulties recovering from impacts in space. They cannot afford the most advanced protections, leaving their satellites vulnerable to accumulating space debris and rising military capability in space (Paikowsky and Ben-Israel, 2011, p. 401). Grzekla and Wagner (2019) contend that incurring greater cost at first can improve the value of the industry in the long run through external benefits, requiring fewer temporary solutions (p. 325). However, when paying an OUF, some nations may not have the funds to maintain their satellites during the time before industry gains take hold. According to Paikowsky and Ben-Israel (2011), an alliance of space-faring countries that offer aid and

protection to nations with non-military intentions can uphold the freedom of space (pp. 402-403). The African Space Agency is a great example of third world countries coming together to establish a presence in space that matches long-standing occupants (Aganaba-Jeanty, 2016, p. 6).

In a different manner, amateur space enthusiasts, such as students, wish to launch satellites into space for the educational benefits. Small satellite missions known as CubeSats are growing in complexity and popularity; they offer a hands-on teaching opportunity throughout the entire life cycle of satellite development (Larsen & Nielsen, 2011, p. 782). An OUF incurs an additional cost that may be insurmountable to many low-budget CubeSat programs. A potential solution to this financial barrier is more student project sponsorship from revenue generating space entities. However, increased competition over educational contracts is antithetical to improving equity in space.

Additionally, the OST as written today does not address student activity in space because there was little, if any, of such activity at the time. If amendments to the OST were to clarify terrestrial property laws for space applications, the changes should be heavily scrutinized since both students and third world countries could be left out again. Grzelka and Wagner (2019) address some potential social drawbacks from a stronger patent system, but there are other possible consequences too (p. 329). For example, not all countries have compatible patent systems, or any patent system at all. Also, most students building CubeSats do not own any intellectual property. Standardizing whether the school, the sponsor, both, or neither, should take ownership and responsibility will help reduce ambiguity in space. For these reasons, social policy in space will not gain traction until the modernization of outer space law.

Hindering Equity: Large Corporations and Militaries

Large corporations and militaries are the social groups chosen to demonstrate the aspirations and actions of those with a long-standing presence in space. They dominate the industry with access to the latest technologies and great influence over the nature of space activities. When these entities use their resources to invent technologies that improve the space industry for all, they are providing social good. Other times, their power inhibits equal Low-Earth Orbit (LEO) access.

An increasing reliance on the commercialization of space has direct effects on the space debris crisis. Broad (2021) documents President Obama's push to leverage the private sector to defend our assets in space; creating smaller, cheaper satellites in greater numbers creates more difficult military targets, ("Washington's Response," para. 5). By the same token, the United States is responsible for most of the objects cluttering Earth's orbits ("Gravity's Pull," para. 3). Currently, space only grows more crowded as satellite contractors develop megaconstellations, hundreds, or thousands, of tiny satellites synchronized together in space to cover a wider area at a lower cost (Hofacker, 2020, n.p.). These advanced technologies only serve to impede equity in space since the wealthy companies producing megaconstellations can simply pay more Orbital Use Fees (OUFs) to occupy more space (Rao et. al, 2020, p. 12759). Without the finances to match large corporations, vulnerable social groups will face greater difficulty asserting their right to launch objects into orbit. Additionally, if orbit space continues to dwindle, corporate satellites providing society's communications or infrastructure needs will gain priority over other projects. Therefore, cleaning up LEO can directly promote social justice in outer space.

When military agendas seep into outer space, namely through anti-satellite rockets and cyberattacks on critical space systems, those tensions inhibit common goals such as sustainability. Encouraging nations to set aside their differences and revisit the outdated Outer

Space Treaty (OST) is quite difficult. Especially when conflict in this uncharted territory moves faster than any arms treaties. In 2007, Broad reported on an anti-satellite missile testing failure from China that resulted in over 800 pieces of space debris (para. 5). Debris from this failure, and similar failures, has the potential to damage satellites that we rely on in everyday life. As a matter of fact, those satellites that are essential to day-to-day operations on Earth make excellent targets in a purposeful military attack, Today, Broad (2021) continues to assert that the general public needs to face the reality of America's vulnerability in space, as demonstrated through bipartisan support for a new Space Force branch of the military ("Washington's Response," para. 20). Forego assumptions that protection in space is solely about style without substance. Take time to understand the complexities of space militarization today. But above all, Broad hopes to bring awareness to the juxtaposition between cutting edge space activity and outdated treaties governing such ventures.

Yet the fear of military activity should not cause nations to discourage equal participation in space. The United States and other nations express concerns that enacting OUFs violate their right to privacy when performing covert military operations and tests (Rao et. al, 2020, p. 12759). Such concerns are worth taking into account, but not at the expense of other social groups. Many privileged social groups in space use privacy concerns as an excuse to deny entry to disadvantaged entities in space (Aganaba-Jeanty, 2016, p. 3). As space becomes more politicized, and orbits become more scarce, social groups outside of the main narrative continue to get pushed out. This exclusion actively violates the existing OST, and any updates should continue to advocate for the rights of all social groups to partake in space activity.

APPLYING LESSONS LEARNED TO SPACE POLICY

With an understanding of the differing perspectives of various social groups vying for orbital use in space, some parallels between congestion pricing and OUFs become apparent. A long-held belief in the freedom of use exists both on the road and in orbit. The first step to effective space debris mitigation is to acknowledge that a fight for sustainability can easily complement a fight for equality (Aganaba-Jeanty, pp. 8-9). Decluttering space makes it less expensive to launch for everyone because a lowered collision risk means less money required for protection and repairs. But as technology improves and orbits clear up, policy can continue to uphold this reinvigorated equality.

Properly vetting through social policy proposals can ensure intangible waste crisis mitigation will not sacrifice equity. For example, congestion pricing promotes more social good with money invested back into vulnerable populations. A similar concept can apply to OUFs if the revenue generated from successful space debris removal were re-invested back into operations for disadvantaged space participants. Offering financial aid for collision resistant technology, establishing a reimbursement program for successful de-orbiting, or awarding grants to underrepresented social groups are a few examples of directing acquired funds to vulnerable populations.

A key difference between traffic congestion and space debris is militarization. The military aspect of space remains highly uncertain, and unlike anything seen on roadways. Correspondingly, congestion pricing cannot serve as an accurate model for how military operations affect implementing OUFs. Other similarly contested mediums with treaties exist, such as maritime law. However, maritime law is even more dated than the OST, and the U.S. Supreme Court has ruled only legislators can make adjustments to these laws (Schwartz, 2020,

n.p.). And Congress has more pressing matters in 2021, between the coronavirus pandemic, social unrest, and a new presidency. Despite a lack of current legislative examples, there are historical parallels between the U.S. and Russia in space today and England and France at sea during the Seven Years War that can influence developing space policy (Brown, 2012, p. 242). Overall, traffic congestion policy offers many applicable insights for space debris mitigation, but further research must occur to account for the current military aspect of space.

USING DATA INTEGRATION AND SOCIAL POLICY TO REDUCE WASTE

As the spacecraft design capstone team continues to work through a technical solution for weather-induced traffic congestion, we recommend proceeding with the conceptual design review scheduled for late April. Upon completion, MITRE's recommendations and our own assessment will influence a discussion of future work directed toward next year's capstone class. This valuation allows incoming students in the course to pick up our work and continue developing the proposed spacecraft.

To supplement technical solutions, policymakers enact social policies that discourage hazardous activities, combining a Pigouvian tax with legal repercussions. Although congestion pricing and Orbital Use Fees (OUFs) appear very different, the latter can learn from the trials and tribulations of the former. Since congestion pricing currently operates in several cities, space policy developers can study these cases and correct course on their own policy before enactment. As indicated prior, reducing intangible waste improves the health, economy, and environment of our society, and the potential gains diminish as timelines lengthen. Good social policy helps speed up the adoption of technical solutions and maintains social justice. We need to hold any potential space debris management social policy up to a high standard of scrutiny to ensure there are no unintended consequences that jeopardize the freedom of space.

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