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Expanding economic activity in space may offer a solution to secular stagnation

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In this speculative article, I argue that the expansion of economic activity in space may offer a uniquely promising way to escape indefinitely from what economists call "secular stagnation," a state of self-fulfilling, persistently sluggish economic growth that has increasingly threatened high-income countries. Economists have pointed to both supply-side and demand-side drivers of secular stagnation, and space as a focal point for investment can—at least in principle—address both. On the supply side, space is an unlimited frontier that, as have frontiers in the past, may inspire the individualism, innovation, and world-building needed to sustainably increase productivity and population growth. On the demand side, public investment toward increased economic activity in space could meaningfully add to aggregate demand if it reached historical peak benchmarks in the United States.

secular stagnation | commercial space | economic growth

In this speculative article, I argue that the expansion of economic activity in space may offer a uniquely promising way to escape indefinitely from what economists call "secular stagnation," a state of self-fulfilling, persistently sluggish economic growth that has increasingly threatened high-income countries.

Modern theories of secular stagnation suggest that sustained escape from it typically requires sharp increases in aggregate demand (from a depressed level) and sustained increases in aggregate supply, for example, through a surge in capital investment and lasting growth in productivity or population. Unfortunately, these requirements have recently proven increasingly hard for high-income countries to satisfy, and a long-term solution seems elusive. On the demand side, long-term declines in the cost of investment goods have not generated a surge in investment demand (1), with market-clearing real interest rates seemingly stuck far below zero. On the supply side, entrepreneurship, productivity, and innovation seem to be slowing (2–4), evidence suggests that economically transformative ideas are becoming more resource intensive to generate (5, 6), and the average fertility rate among OECD countries has fallen from 2.84 to 1.59 (well below replacement levels) over the half-century from 1970 to 2020 (7). Although the COVID-19 pandemic obscured concerns over secular stagnation from 2020 to 2022, and interest rates have risen sharply of late, the forces behind secular stagnation are likely to reassert themselves once the pandemic—and the massive fiscal and monetary stimulus it generated—has passed.

A concerted effort to expand economic activity in space has the perhaps unique potential, at least in principle, to address indefinitely both the demand and supply roots of secular stagnation. In brief, the potential is as follows. On the demand side, if the United States were to return to its historical peak levels of public-sector investment in space—as a share of federal government outlays or gross domestic product—it could directly add between \$1.5 trillion and \$3 trillion to demand over the next two decades and indirectly add, by inspiring private-sector investment in expanded space activities, potentially much more. On the supply side, space might serve as a new and essentially infinite physical frontier, spurring dynamism, innovation, and thus productivity growth as have frontiers throughout history, but this time with no end point. Similarly, expansion into space is humanity's only real option for sustained population growth in the long run. As far as I am aware, only space offers this combination of attributes.

To explain this potential a bit more, I start by briefly describing the idea of secular stagnation and leading explanations for its reappearance in developed economies in the late 20th and early 21st centuries. I then summarize the reshaping of the space sector over the past two decades and discuss the features of the sector, noted above, which may make it a promising path for escaping stagnation traps. I put special emphasis on Frederick Jackson Turner's (8) well-known theory of the frontier as a source of innovation and how space—colloquially known as the "final frontier"—fits with it. I close with observations on the scale of historical public investment in space to quantify the potential size of a policy intervention.

1. Secular Stagnation: A Brief Primer

The secular stagnation hypothesis first appeared in the late 1930s, when Alvin Hansen noted—in his Presidential address to the American Economic Association—a risk of "depressions which feed on themselves," a natural subject given the decade the global economy had just experienced.

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The phrase "secular stagnation" was meant to capture both the persistent nature of the threat and its core feature, namely slow or negligible economic growth.

Low and declining economic growth rates across high-income countries over the past few decades have revived interest in the secular stagnation hypothesis, especially as relations between the United States and a rapidly growing China have become more contentious. The average real growth rate in the OECD, according to official OECD data, fell from 4.5% over 1960 to 1979, to 2.9% over 1980 to 1999, to only 1.8% over 2000 to 2019. And averages obscure the dramatic case of Japan, for which these three figures were 7.2%, 2.9%, and 0.7%, respectively. Many commentators, including leading macroeconomist Lawrence Summers (9), have warned that the rest of the high-income world is in danger of "Japanification" if the threat of secular stagnation is not met. The corresponding figures for the United States, for example, were 3.9%, 3.3%, and 2.0%.

What is the secular stagnation hypothesis? In simple terms, secular stagnation is the idea that a sluggish outlook for the economy causes people to save more and firms to invest less, and if interest rates cannot fall enough to spur investment (perhaps because of the sluggish outlook), the lack of investment makes the low-growth prospects all the more likely to be fulfilled, initiating a vicious cycle. Buried in that seemingly simple statement are a number of steps that macroeconomists try to model formally, so as to be sure that they understand the mechanism. For example, Robert Gordon (10) describes the mechanism as follows, "Slower growth in potential output from the supply side, emanating not just from slow productivity growth but from slower population growth and declining labor-force participation, reduces the need for capital formation, and this in turn subtracts from aggregate demand and reinforces the decline in productivity growth. In the end, secular stagnation is not about just demand or supply but also about the interaction between demand and supply."

Gordon mentions demand and supply because his view starts with what economists call "supply-side drivers," such as productivity and population growth, but requires us to have a theory of why demand does not step in to save the day. Summers (11) provides a different description of the core mechanism which does just that, stressing the role of what economists call the "zero lower bound" on nominal interest rates. Summers stresses interest rates because they are supposed to automatically adjust to help a sluggish economy self-correct. In particular, when there is less reason to invest—for example, because productivity or population growth is low—we expect the supply of investment funding to exceed the demand for it, pushing down the cost of funding, namely nominal interest rates. If nominal interest rates fall, we in turn expect the inflation-adjusted cost of funding—what economists call the real interest rate—to fall as well, and thus spur demand for investment. That is, we expect the economy to self-correct.

A problem can arise, however, when conditions are such that the real interest rate would need to fall well below zero to spur investment enough to spring an economy out of a stagnation trap. Nominal interest rates cannot fall (much) below zero because no one will lend cash at negative rates, and this "zero lower bound" on nominal interest rates means that real interest rates may also have a floor below which they cannot fall, especially if a sluggish economy generates deflationary pressure. If real interest rates cannot fall enough, investment remains too expensive, and the economy gets stuck in a low-growth stagnation trap. As suggested above, modern high-income countries with low population and productivity growth may find themselves in precisely these conditions. Or, in Summers' own words: "…if one assumes that investment is a decreasing function of the interest rate and that saving is an increasing function of the interest rate and that the level at which equilibrium with full employment takes place requires a negative nominal interest rate, then adjustment will take place in the form of a lower level of output, and that lower level of output may continue indefinitely."

How does such a vicious cycle get started? Answers rely on a similar mix of supply-side and demand-side reasons. To Gordon, the slowdown in productivity and population growth over the past several decades—which are themselves products of myriad factors—are to blame. Summers makes room for these factors, but he adds that demand-side factors—such as the falling relative price of capital goods and capital intensity of leading firms' technological innovations, as well as persistently low inflation and nominal interest rates—depress investment demand relative to saving and are sufficient to get us into trouble on their own.

And how can it be stopped? Gordon's analysis would imply a focus on increasing productivity and population, as the higher growth rates they would engender would spur private investment and initiate a virtuous cycle through the secular stagnation mechanism run in reverse. Summers (11) stresses demand-side stimulus, noting that Hansen's dire predictions were not borne out immediately because "Hansen wrote before he knew there was going to be a Second World War, a baby boom, massive investments involved in creating modern suburbia, and a large-scale increase in the role of government…" and that, in the current situation (of 2015), "I find it hard to make a rational case against a substantial increase in public investments in Europe and in the United States."

Interestingly, although it is not often stressed, the practical implications may be quite similar whether one subscribes more to the supply-side or demand-side mechanism, namely to spur private investment, perhaps through public investment, in capital-intensive, productivity-enhancing, and population-increasing projects, at a massive scale. Summers, in particular, stresses infrastructure such as airports and roads as a prime target for the sort of action he recommends. Kevin O'Rourke (12) stresses new "green" infrastructure as a path forward (in response to environmental threats that may themselves worsen secular stagnation): "If the scientists are to be believed, and I assume that they are, then climate change is the biggest single threat we face today. Heading it off is going to require investment in a whole host of energy and transportation related sectors."

2. Space as a Focal Point for Combatting Secular Stagnation

As the discussion above suggests, space meets a number of qualifications required of a focal point for investments to overcome secular stagnation, and it has some unique characteristics that arguably increase its potential. Before turning to these features, however, we provide a brief primer on the recent revolution in the modern space sector for those not familiar with it. Additional details can be found in Weinzierl (13) and the many references cited therein.

2.1. The Twenty-First Century Rise of Commercial Space. The Space Age began with the Soviet Union's launch of Sputnik in 1957. The subsequent decade saw enormous investments by both the Soviet Union and the United States on "space race" programs, most famously the latter's Apollo program that landed astronauts on the moon in 1969. For the next several decades, these two governments and (to a lesser extent) others built space programs focused on providing what economists call public goods, namely national security, the pursuit of basic science, and exploration of space (14). Consistent with these objectives, public-sector institutions—both civilian (such as NASA) and military (such as the US Department of Defense)—designed, directed, and funded these programs. Much was accomplished, from the Space Transportation System (the "Space Shuttle"), to scientific instruments such as the Hubble Telescope, to the International Space Station, the crowning jewel of the first half-century of the space age and an effort that brought Russia and the United States, among many others, together in a hopeful symbol of the power of space to transcend terrestrial divisions.

Despite the achievements of the first 50 y in space, failures of the Space Shuttle and a perceived slowing of innovation in the sector eventually led to a shift away from the government-led model toward decentralization and commercialization. A crucial inflection point was the Commercial Orbital Transportation Services (COTS) contracts of the mid-2000s, in which NASA changed its approach to working with private space contractors along a few key dimensions. First, the agency awarded fixed-price rather than cost-plus contracts and awarded those contracts to multiple providers, changes that powerfully incentivized efficiency and increased competition. Second, the agency moved from providing "oversight" to "insight" for its contractors, freeing them to act with fewer constraints, cut costs, and speed production. Finally, NASA looked to become "one customer among many," explicitly urging companies to build products that would have other customers (and allowing them to retain the intellectual property that would make that possible). These changes, along with crucial technological advances that lowered the cost of space activities, led to a surge of private-sector entrepreneurship, investment, and success in the sector. Most famously, SpaceX quickly rose to become the globally dominant launch provider, progressively driving launch costs down by an order of magnitude from the days of the Space Shuttle through innovative management, production, and organizational practices. Edgar Zapata, a NASA engineer, estimated that resupply of the ISS using SpaceX cost less than half what it would have cost had NASA followed its previous practices (15).

Private investment capital has aided this transition, with as much as $270 billion fueling a boom in space businesses across a wide range of technologies over the past decade, according to data from Space Capital (16). SpaceX and Amazon have invested tens of billions of dollars themselves in building out satellite constellations, promising a new set of Earth observation capabilities and enormous potential for data processing, communications, and transmission at scale. The revolutions in launch and technology costs have also led to early steps toward building a more holistic space infrastructure, from refueling depots in space, to sustained lunar operations, to commercial space stations.

In this reshaped approach to space, the public and private sectors play complementary roles in driving innovation and progress. Public-sector actors—both civilian and military—continue to be the largest source of funding for fundamental research, exploration, and other activities that the marketplace has difficulty supporting at efficient levels, thereby providing a foundation of discovery and innovation upon which private actors can build. In turn, the private sector's inherent dynamism and discipline help public-sector actors to pursue their goals more efficiently, namely through mechanisms that share key components with the COTS program. These private actors also bring their own, commercial objectives to space, expanding the range of activities that can be funded and pursued.

I now turn to describing why this reshaped space sector is promising as a focal point for an investment push to avoid secular stagnation. I consider both the supply and demand side of secular stagnation as described above.

2.2. Supply Side: Space as a Frontier to Drive Productivity and Population Growth. Economists have pointed to low rates of productivity and population growth as key supply-side drivers of secular stagnation in high-income countries. I consider how expanded activity in space might address each.

First, supporters of space exploration often tout the foundational technologies that rely upon and have been developed in space (e.g., refs. 17 and 18) as well as the economic activity supported by space activities more generally (19). The extreme environment of space and the high cost and complexity of launch have made innovation crucial to activity in space; NASA (20) officially cites camera phones, LEDs, portable computers, and even athletic shoes as a few of the "20 things we wouldn't have without space travel" and lists such as that omits ubiquitous technologies that rely on space such as the Global Positioning System (GPS) and satellite-based communications. Extrapolating from this experience, we might hope that the expansion of economic activity in space would continue to generate dramatic breakthroughs and inventions, driving productivity growth both in space and on Earth (21). Such hopes are made substantially more plausible by the rise of commercial space discussed above and the consequent shift toward a space sector that combines the power of public-sector investments in fundamental research and exploration with the market's power to drive innovation and productivity—what McCloskey (22) calls its "innovism." Ideally, this sector will be able increasingly (and sustainably, likely with the help of domestic regulation and international agreements) to tap into resources in space–such as rare Earth elements, space-based solar power, and the unique research environment provided by the vacuum and microgravity of space—to drive economic development, as was the case for the US manufacturing sector in the early twentieth century (23).

One explanation for why space has generated, and could continue to generate, so much innovation is that space is a classic "frontier" environment in the words of Frederick Jackson Turner, an American historian who famously argued in an 1893 essay that America's economic and cultural dynamism had their roots in the persistent growth of the country into frontier territory (which he warned had just reached its conclusion). While Turner's narrative has been complicated in recent decades by those—notably Patricia Limerick (24)—who emphasize the tragic side of American expansionism into territories viewed as homelands, not frontiers, by indigenous peoples, his idea that expansion into a challenging and new physical space drives growth lives on as conventional wisdom for many.

The idea of space as an inspirational frontier is widespread. The influential television and movie series Star Trek made famous the phrase: "Space, the Final Frontier." New York Times columnist Ross Douthat (25) has celebrated the potential of space to reverse societal decline, writing: "I suspect that a truly globalized civilization cannot help tending toward decadence so long as it remains earthbound, so long as there is no hope of finding actual new worlds to leap toward, conquer, or explore... So if we want to really escape decadence... we need to find a way to climb, to make a ladder to the stars, and to offer future generations of humanity a new reality to explore..." And Turner's thesis was explicitly linked to space by NASA's own Chief Historian Stephen J. Dick, who wrote: "The Western frontier closed about 1890, but Americans found a new one in space." (26)

But what is the mechanism through which this frontier theory might operate? Though admittedly speculative, we can use recent academic research on the effects of the frontier to suggest a two-step mechanism with particular relevance given the current shape of the commercializing space sector and the context of secular stagnation.

First, Bazzi et al. (27) "shows that the American frontier gave rise to a persistent culture of rugged individualism." Specifically, they measure exposure to the American frontier at the county level from 1790 to 1890 and measure individualism using the relative prevalence of infrequent children's names in frontier territories. They describe the idea as follows, "The foundational contributions... associate individualism with several related traits: a view of the self as independent rather than interdependent, emphasis on self-reliance, primacy of self-interest, and regulation of behavior by personal attitudes rather than social norms." They find that "Long after the closing of the frontier, counties with greater TFE [total frontier exposure] exhibit more pervasive individualism."

It is of course debatable whether expanded space activity would generate the same (or effectively similar) rugged individualism as did the Western continental American frontier. Reasons for skepticism exist: the exploration of space is exceedingly dangerous, and at least its early stages are likely to be dominated by small groups whose members are highly coordinated, interdependent, and hierarchically commanded. But like all frontiers, space will attract those individuals who are willing to take on great risk to pursue a new way of life and new resources (which, in space, may include not only material resources but new settings, such as a vacuum with microgravity). They may face different dangers than the pioneers before them, but frontiers have always been dangerous, and those who overcame the dangers of prior frontiers have appeared to pass on their determination and rugged individualism to those who follow. It seems reasonable to expect that space as a frontier would have similar effects.

Importantly, the rise of commercial space over the past two decades is likely to reinforce the culture of rugged individualism in an expanded space sector. The shifts described above—from a centralized space sector with little competition to a sector that includes both public-sector activities and decentralized, competitive, "arms-length" activities—empower smaller firms and individuals by upsetting the established order. These shifts also require private actors to bear more risk than before, arguably encouraging some of the ruggedness that characterized past pioneers.

Second, in this journal, Gorodnichenko and Roland (28) provide strong evidence of a causal effect of individualism on income per worker, total factor productivity, and innovation, writing: "Countries having a more individualist culture have enjoyed higher long-run growth than countries with a more collectivist culture. Individualist culture attaches social status rewards to personal achievements and thus, provides not only monetary incentives for innovation but also social status rewards, leading to higher rates of innovation and economic growth." Related, and also in this journal, Leonard and Smith (29) use the Bazzi et al. data described above to show that individualism is positively related to measures of economic mobility across US counties. Together, these findings suggest that the effects of individualism operate at the macro and micro levels to generate more dynamic economies.

Thought of as a "country" of its own, the commercial space sector that arose over the past two decades has a culture that prizes innovation and rewards individual success. Many date the start of the sector's recent rise to the $10 million Ansari X prize, awarded in 2004 to a company led by celebrated aerospace designer Burt Rutan. British billionaire and entrepreneur Richard Branson bought the rights to Rutan's design, making it the basis of Virgin Galactic's race to develop space tourism. And Branson is far from alone: Jeff Bezos and Elon Musk—two of the world's richest individuals and both entrepreneurs—founded and lead the two most prominent new launch companies of the past two decades, Blue Origin and SpaceX. Hundreds of space startups form each year, funded by a growing space-focused venture capital sector that is moving space from an industry dominated by enormous diversified government contractors with steady growth to a fast-paced, rapidly changing sector with many spectacular failures and a few spectacular successes, much like the "technology" sector of the past few decades. The direct involvement of many of that technology sector's leaders in space—and the increasing numbers of talented young people choosing to start space companies—suggests just the dynamic environment that the research on historical frontiers has identified as helping translate individualism into innovation.

Additional research finds that the relationship between individualism and growth is stronger in low-growth environments. In fact, despite the studies cited above, the evidence on the effect of individualism on innovation and growth is not definitive, with some researchers finding uncertain or even negative relationships. Recent work by Mostaghel et al. (30), however, uses Bazzi et al.'s measures of individualism to "demonstrate the greater (limited) value of rugged individualism in low (high) GDP growth conditions in driving entrepreneurial activity." Together, these studies suggest that this two-step mechanism may make space as a frontier particularly relevant in an era of secular stagnation.

Aside from its potential to increase productivity growth, space is uniquely capable of addressing a second driver of secular stagnation: declining population growth rates. Among others, Tyler Cowen (5, 31) has argued that declining population growth is both a symptom and cause of economic and cultural stagnation in high-income countries. And the data are striking. According to the OECD, all seven members of the G7 group of high income countries had fertility rates greater than 2.0 in 1970, while none of them exceeded 2.0 in 2020, and the average of the seven countries' fertility rates dropped more than one-third, from 2.33 to 1.51, over this half-century. This dramatic shift—from above to below replacement levels—portends a long-term transition to low population growth as more of Earth's nations reach the standard of living of today's high-income countries.

Space has a unique potential to encourage population growth, but not by relaxing constraints on land or resources; after all, it is not primarily for those reasons that fertility rates are declining on Earth. Rather, the expansion of economic activity in space would, though perhaps not for some time, include the creation of new worlds with their own robust populations (32) and new technologies to sustain them (which, ideally, will also increase the sustainability of life on Earth). Increased investment in the technologies to enable space settlement would therefore be consistent with the analysis of Jones (33), who has shown formally how the benefit of further growth in consumption may decline enough in high-income countries that their priorities shift toward lowering the risks of civilizational disaster. The possibility that space settlements could eventually drive humanity's population growth may sound outlandish, but it took more than 250 y from the first British settlement of what became the United States for the latter's population to exceed that of the United Kingdom; at 25 y, we are only one-tenth as far from when the first permanent habitation in space began aboard the International Space Station.

It may be of interest to note that Alvin Hansen, the father of secular stagnation theory, was himself focused on the role of the frontier: O'Rourke (34) tells us "The late 19th century expansion of the American frontier, and the waves of railway investment that accompanied it, were constant themes in Hansen's work." Backhouse et al. (35) tell us:

> The expansion of the frontier had sustained investment for a century. After the closing of the frontier, demand for investment came from technological advance: motor vehicles and electricity stimulated the building of a vast infrastructure, sustaining demand in the 1920s. The Great Crash of 1929 may have originated in finance and the collapse of speculation, but its consequences were severe because the stimulus from these industries was at an end. Declining population growth and the absence of new industries meant a dearth of investment and a period of stagnation. The immediate origins of the crisis might be short-term, but its severity was the result of long-term structural factors... Hansen took the idea of the New Frontier quite literally...

2.3. Demand Side: Expanding Economic Activity in Space Will Require Large Capital Investments. To address the demand side of the secular stagnation challenge, economists have emphasized the power of a substantial increase in investment—that is, purchases of physical capital that can be used in production—funded either through the public sector or by private companies.

Any sustained expansion of economic activity in space will require investment in physical infrastructure on a massive scale. Space is often referred to as an industry or sector, but especially in the context of this article, it is important to remember that it is more properly thought of as a place. The economic development of space will therefore require investment in infrastructure to support trade with existing places (e.g., imports from Earth as well as exports to Earth of goods manufactured or services produced on-orbit, space-based solar power, and tourism) and to support the functioning of the economy in space itself (e.g., habitation, food and water generation, and security).

Today, the infrastructure of space is largely nonexistent, but one can forecast the components, and they are predictably capital intensive. A NASA-sponsored study (36) recently detailed a "high-level, logical breakdown of the current (and envisioned near-future) commercial space economy." It included, among many others, the following components: launch services; habitation systems; in-space transportation systems; planetary entry, descent, and landing systems; spacecraft development; ground site development; in-space manufacturing systems; orbital debris tracking and removal systems; space resource extraction technologies and systems; and an array of satellite systems and satellite servicing systems. As noted above, private-sector actors are already devoting tens of billions of dollars to investment in some of these areas, especially large satellite constellations (such as Starlink from SpaceX and Project Kuiper from Amazon) and the next generation of space stations being built by several teams as part of NASA's Commercial LEO Destinations Program. Moreover, beyond this list are even more ambitious—and capital-intensive—projects, such as settlement construction on the Moon and Mars, enormous space-based solar power arrays, and large-scale manufacturing facilities to move heavy industry off Earth (the often-stated goal of Blue Origin's Jeff Bezos). And these peaceful, economic uses of space will proceed alongside a growing national security focus on, and investment in, space capabilities by the US government and its allies if relations with past space power Russia and rising space power China remain adversarial.

How large would these investments need to be to matter for secular stagnation? The answer depends, of course, on both the depth of a stagnation trap and the type of expansion in space economic activity pursued, but accomplishing a large share of the components mentioned above would certainly require trillions of US dollars over the next several decades. Elon Musk has estimated his envisioned city on Mars could alone cost $10 trillion to build (37). By way of reference, total annual investment in the United States, as reported in the Bureau of Economic Analysis national income accounts, is approximately $5 trillion. Thus, to meaningfully increase investment demand over extended time horizons requires projects that will cost trillions of dollars to complete.

Is public funding necessary, or can the large and growing private space sector fund this expansion alone? The vast majority of the current space economy revolves around satellites that provide, for example, telecommunications, geolocation, Earth observation, and internet services: Bryce (38), for instance, estimates that 72% of total space revenue and almost all of private space revenue were tied to the satellite sector (see ref. 39 for an analysis of the specific industries using space services and a narrower definition of what constitutes space sector revenue, or gross output). A dramatically expanded space economy—that is, one that can help address secular stagnation—would go far beyond satellites, as discussed above. In sum, while the private sector may be capable of funding these activities, public-sector funding would jump-start and accelerate their development, just as it did for the earliest days of space activity.

We can turn to history to provide benchmarks on the scale of investment in space that may be both feasible and required. Specifically, we consider two such benchmarks, one that translates to today's economy the average (or peak) levels of spending on NASA's lunar programs from 1960 to 1973 and one that uses the gap between overall NASA spending from the same period and its subsequent 50 y to estimate how much more would have been spent had the early surge level been maintained.

The historical peak of public investment in expanded space activity came during the lunar programs of the 1960s and early 1970s. In a detailed analysis of NASA budgets, Dreier (40) calculates that the lunar programs cost $28 billion in nominal (at the time) dollars from 1960 to 1973. Translating historical spending magnitudes to present conditions can be done in multiple ways, each of which reveals different information. Adjusting for inflation ensures that our intuitions about a dollar today resemble those of someone from the relevant past period in terms of what it can buy (i.e., the price level). Using, as did Dreier, NASA's own inflation adjustment calculator, we can convert the 14-y $28 billion nominal figure to $309 billion—or approximately $22 billion annually—in 2022 US dollar terms. But inflation adjustments fail to ensure that our intuitions about magnitudes relative to the overall size of government or the economy resemble those of someone from the relevant past period. The US government and economy both have grown faster than inflation over the decades since the lunar programs, so if we want to understand the magnitude of investment the lunar programs represented as a share of government spending or overall activity, using inflation adjustments is insufficient.

Dreier's data series on lunar programs spending shows that it rose from 0.07% of overall government outlays and 0.01% of gross domestic product (GDP) in 1960 to peaks of nearly 3.2% and 0.5% respectively in the mid-1960s before coming back down to the 1960 levels in 1973. As shown in Table 1, if the US government were to return spending to the average levels of lunar program spending over 1960 to 1973, the equivalent annual expenditure would be $82 or $62 billion using 2022 levels of government outlays or GDP, respectively. Still more striking is if peak expenditure levels reached during the lunar programs were resumed, a scenario made all the more possible by the return of geopolitical tensions among space powers that drove public investment in the initial space race. Using the same conversions, peak annual expenditure on the lunar programs reached in the 1960s is the equivalent of $186 billion and $131 billion in annual expenditure in 2022. Of course, these numbers would grow over time if spending grew proportionally to real outlays or GDP. In other words, spending $1.5 to $3.0 trillion over the next two decades to expand space activity would not be out of proportion to the spending on lunar programs at the peak of the first space race. Note that these numbers refer to public-sector investments only, which experience over the past two decades suggests would be magnified as the private sector capitalized on them to expand their reach and services for commercial customers.

A second benchmark comes from calculating how much hypothetical public investment might have occurred had it not fallen below the levels of the 1960s and early 1970s. Total NASA spending averaged 2.36% of federal outlays and 0.43 percent of GDP from 1960 to 1973, while over the subsequent 50 years, these figures were 0.75% and 0.15%. These figures imply that if NASA budgets had been maintained over that half-century at their earlier levels, a cumulative total of 81% of average annual federal outlays and 14% of average annual GDP would have been spent on space in addition to NASA's actual spending. Some of that gap is likely to have been filled by US national security spending on space, which in recent decades has been roughly equivalent to NASA spending. Nevertheless, these calculations imply gaps, scaled to the size of the 2022 US economy, of at least $1 trillion and as much as nearly $5 trillion. While we cannot know what this additional funding would have made possible, and the centralized model of the sector may have constrained its effects over much of the past half-century, today's reshaped sector would likely respond strongly to a surge

Table 1. US Government space annual expenditure benchmarks ($ billions)

	To match average of lunar programs spending	To match peak of lunar program spending
Dollar value of spending	22	45
Share of total US outlays	82	186
Share of US GDP	62	131

Source: OMB (41), Dreier (40). Note that NASA 2022 outlays were approximately $24 billion.

of public investment in space that made up for some of this historical gap.

3. Conclusion

An expansion of economic activity in space is far from the only attractive opportunity for large-scale public investment. In the United States, for example, alternative targets include updating the country's aging physical infrastructure, effecting a conversion of the energy sector to renewable sources, and pursuing new opportunities in artificial general intelligence and nuclear fusion. Each of these options might yield enormous benefits to society and be worthwhile public investments. Moreover, from the narrower perspective of this paper, each of these options has features that would address aspects of secular stagnation.

Space, however, is unique. Expanding economic activity in space literally involves world-building and thus can credibly sustain capital-intensive investment and population growth at an unlimited scale. Moreover, it is an effectively infinite frontier, so it can postpone indefinitely the exhaustion of terrestrial frontiers experienced over the last century. While we can only speculate as to how a large investment in the expansion of economic activity in space would affect us, and it is imperative that we expand into space in a more sustainable and ethical manner than past settlers expanded into what they saw as their frontiers, space has a unique potential to usher in a new era of dynamism, innovation, and growth.

Data, Materials, and Software Availability. All study data are included in the article and/or supporting information.

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