Science and Society in the Long View: Neal Stephenson's Anathem *as a Simulation of the Governance of Science*

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Introduction

What is the ideal relationship between science and society? How do short-term and long-term approaches to research change the dynamics of scientific work? What effect does centralization or decentralization have on the practice of science and its regulation? Are there other ways of organizing the scientific enterprise that could produce better outcomes for society? Science fiction can explore answers to these questions and other aspects of science policy. I propose that Neal Stephenson's novel *Anathem* offers a rich and unique examination of how science and society should relate.

Stephenson has been a longtime student of innovation and of the US space program. He has published articles such as his 2011 "Innovation Starvation" that call for much deeper and long-term thinking about innovation policy. Many look to Stephenson as a source of inspiration for thinking about science policy issues writ large; his 1992 novel *Snow Crash*, for instance, is often cited for its portrayal of an online metaverse. However, *Anathem* offers significant fodder for a broader reflection on science and policy, as Stephenson carefully thinks through an alternate way by which science and society could relate, with a particular focus on how science and society would interact across many thousands of years.

Stephenson's consideration of the long-term impacts of science and how to govern it raises questions that are not well captured in broader science policy literature. In this paper, I first discuss how science and engineering policy shapes how science and society relate; then I summarize research approaches that examine how science fiction can help improve the scope and practice of science policy, in particular by informing our imaginations to reflect on what world we want to create. Then I discuss *Anathem* as a science fiction novel of grand scope about scientist monks who live under a drastically different science policy infrastructure, and I review the book's backstory of thousands of years of struggle between civilization and science. I conclude by exploring how the book's denouement gives conflicting answers about how science and society should ultimately relate. While Stephenson might describe the policy implications of his book as "impressionistic," *Anathem* offers readers a thought experiment to imagine vastly different approaches to science policy—and should be celebrated and recognized as such.

Science, Technology, and Engineering Policy Shapes the Future

Many science fiction readers and scholars track updates in science and engineering, and many are scientists and engineers themselves. Less commonly explored in science fiction and

among its readers are the institutions and policy choices that shape what scientists and engineers actually do. There is a constellation of people who "do science policy" by shaping the approaches, resources, and culture of science and engineering. These professionals include staff at federal agencies[2] such as the US National Institutes of Health; Congressional and Presidential staff engaged in science and technology policies and legislation; ethicists, anthropologists, and science, technology, and society (STS) scholars who study the conduct and practice of science; program officers at philanthropies, investors, and other funders; as well as many other decisionmakers who shape how science is used to perform missions like national defense, water remediation, disaster preparedness, etc.; along with innumerable others. I colloquially refer to all these people as "science policy practitioners," while also embracing science policy scholar Daniel Sarewitz's holistic approach to defining science policy as shaping the outcomes of science by interrogating its values and inputs (Sarewitz 2007).

The aspect of *Anathem* that I focus on here is the story's depiction of how science and society should relate, a topic long examined in science policy research in part through discussion of a "social contract for science". (Guston 2000a, Kevles 1995) Such a social contract addresses the question of how the collective science community—in which I include, along with scientists, both engineers and technologists, who may outnumber scientists themselves—relates to and potentially serves society.[3] Given that the public sector is often the primary funder of science, society can reasonably expect benefits now and in the future in exchange for funding and support—but there are deep debates on what the nature of those benefits should be and when they should occur.

The idea of what benefits and responsibilities are entailed in a social contract[4] can be quite broad and occur over a range of timespans. Science policy in the United States after World War II invoked one vision of the contract: Taxpayers would support curiosity-driven research at universities, which would provide new insights that are intrinsically worth knowing; some of that research would yield results that could be translated into social benefits such as solving a specific societal problem, creating a useful new technology, or generating economic activity.

The process of deciding what science and engineering is sufficiently beneficial to be worth funding is complex and often highly uncertain. Scientists can disagree about whether a piece of curiosity-driven research is actually worth knowing, as well as disagree about what the practical benefits of research will be in advance of—or even after—a research program's completion.[5] Funders and researchers who seek practical benefits do so with a range of desired timespans as well, with some seeking a quick return, which could be economic or societal, and others looking for some promise of future benefit.

We need different conversations about how science and society should relate. Political scientist and science and society scholar David Guston called to retire the social contract for science, to move beyond vague ideas of mutual obligation and assumedly-guaranteed benefits and to instead find ways for people and institutions to better collaborate and get better outcomes. (Guston 2000b).Guston overviewed how the US Congress began to impose oversight on the institutional

design and grantmaking process for scientific and engineering work, creating "boundary organizations" that link science organizations and political groups (Guston 2000a). More recently, the 2022 CHIPS and Science Act calls for the National Science Foundation to more proactively encourage engagement with "ethical and societal considerations" of its funded research.[6]

Oversight and getting results for a given area of science can depend greatly on the nature of the activity. Sarewitz and Nelson argue that some areas of science and engineering struggle to make long-term progress, such as with health care outcomes, and that exponential efficiency akin to Moore's Law in semiconductor development is not possible in most industries (Sarewitz and Nelson 2008). This raises questions about how to actually make technical progress across the long-term. Research on responsible innovation and innovation studies more generally has been working to explore better ways to shape science policy for public benefit across all industries, for longer-term benefit.[7] However, very little of this literature focuses on how science and society might relate into the very distant future.[8]

There is one extreme of the science and society debate that is worth keeping in mind when reading *Anathem*. Michael Polanyi's "Republic of Science" (1962) argued for the independence of science. Polanyi contended that science inherently pursues objective knowledge, and that this pursuit should be supported and funded seemingly at any cost. This perspective is echoed in contemporary calls to significantly increase funding for scientific research,[9] reflecting a belief in science's transformative potential. Polanyi claimed that the scientific community operates as a self-organizing system. He argued that scientists, through informal networks and communication, are able to track each other's work and collectively guide the direction of research, with each researcher focusing on problems suited for their skills. This regulating process allows the scientific community to allocate its resources efficiently and focus on problems best suited to individual and collective expertise. Polanyi's vision places trust in the motivations and collaborative nature of scientists to assume that they will advance knowledge without the need for external controls or directives from government. There are many critics of this idea, who note that scientists can be inefficient with funding when left to their own devices, and that in a democracy, all funding should be tied to legitimate elected leaders (Guston 2000a). Further, if Nelson and Sarewitz are right that some areas of science are making little progress, this might be evidence that Polanyi's vision of independence may not work as he hoped.

Science Fiction as a Way to Explore How Science and Society Should Relate

Science fiction can be a great boon for debating how we collectively should want science and society to relate. Several policy scholars have called on science fiction to help imagine and think through future policy choices about science. Notable contributions to this tradition include Miller and Bennett (2008), York and Conley (2020), Finn (2025), Fritzsche and Soldner (2025), and Older and Pirtle (2019).[10] This approach does not focus on the predictive accuracy of science fiction, but instead highlights the genre's utility as a tool for exploring the values and principles we might wish to apply to future decisions about science. Older and Pirtle, for instance, discuss using

science fiction stories as informal simulations, exploring how things might be different if society were composed differently and/or if technologies were shaped and built in different ways (2021). Reflecting on such alternatives can be extremely useful for the governance of science, with science fiction stories serving as proxies for and thought experiments about deeper governance principles, philosophies, and worldviews.

Neal Stephenson's *Anathem* as a Simulation

Neal Stephenson's science fiction novel *Anathem* (2008) provides a rich analogy and an informal simulation tool for exploring the relationship between science and society. Stephenson's technical depth and research, along with his focus on long-term progress in innovation, has made his work of particular interest for some science and society researchers. In *Anathem*, he describes scientist-monks living apart from society in separate disciplinary conclaves called "maths," with their work and existence a point of tension over the thousands of years of backstory described in the book. Its length, approaching 1,000 pages in various editions, reflects its ambitious scope.[11] Here, I will make only indirect references to general plot points that will not spoil the story for a prospective reader. Instead, I focus on the background of the book's world and how that might inspire us to think more deeply about science and its relation to society.[12]

While some science fiction examines various permutations of how scientists exert control or are controlled by society,[13] as well as how they relate to society, it is rare to encounter a work in which this relationship is central to the story, as it is in Anathem. And yet very little attention has been given to the novel as a science policy allegory (although I did write on this topic back in 2011). Interestingly, while Stephenson extensively explores philosophical influences in the book—recounting the history of Western philosophy from Thales and Plato to Kant and beyond—he does not explicitly discuss any influences on his science policy framing in the novel. It would be fascinating to know his influences, though he has had sufficiently deep engagement on innovation policy to indicate that he is a serious thinker on the topic.[14]

Anathem conjures a world in which scientists are kept apart from society, with strictly governed yet volatile connections between science and society. The scientists in *Anathem* are largely independent, yet they seem to relentlessly deliver new technology and theoretical insight, despite efforts by society to regulate them. It effectively is the Republic of Science that Polanyi sketched out, where the maths have autonomy but one whose political status and power in contrast to the outer world is changing greatly over time.

Background on the Mathic World of Scientist-Monks

Many reviews of *Anathem* discuss the eccentricities of the scientist-monks that exist on the fictional world of Arbre. These monks—called the "avout"—can be imagined as a cross between members of a religious order and university professors or students with varying levels of expertise and types of research. Their collective community is called the mathic world. The avout live behind walls, separated from the outside, "Saecular" world, in self-sufficient villages called

"concents." The avout must take vows that in some ways are absurd,[15] including becoming sterile and forgoing life with families outside the maths. They are taught that the outside world has varied preconceptions of who they are and what their intent is.[16] Their primary goal and purpose is to perform research and create new knowledge. Many of the people inside the maths have additional practical skills and hobbies that are often useful, such as farming, craftwork, and others that enable their basic needs to be met. This seems to help the maths be economically self-sufficient, although they surely occupy valuable stretches of land and buildings.

The Saecular world has overthrown the mathic world many times, especially when technologies developed in the maths cause trouble and disruption for the broader society. The characters in Anathem emphasize on several occasions that the maths are only permitted to exist on the sufferance of the Saecular world, even though the avout live outside the Saecular legal system. The protagonist narrator of the book, a young avout named Erasmus (or "Raz"), pointedly refuses to discuss the dynamics[17] and politics[18] of the Saecular world, (445) which he views as too fickle and changing to be worth describing, whereas the mathic world persists always as a realm focused on intellect, contemplation, and scientific inquiry.

The book's focus on the separation of the maths from society is what made me interested in Anathem as an informal simulation for considering science policy. The sites of the avout are partitioned into different kinds of maths, based on the level of focus and depth of the research questions of the avout inside. The different maths operate on a series of time scales at which point they open their doors to the Saecular world and to other maths to share their research and potentially bring in new avout. There are Unarians, whose maths open their doors to the world and allow for exchange with the outside world every year;[19] Decenarians, whose maths open every 10 years; Centenarians, whose doors open every 100 years; and Millenarians, whose doors open every 1,000 years. These maths are not only isolated from the outside world but also from each other, with one of each kind of math being located at a single monastery-like site but kept in separated wings.

The supposed purpose of the time-division of the different maths is to allow researchers to focus on correspondingly longer-term problems. The Unarians' focus allows for study across a few years doing things such as writing theses summarizing research about cosmology, taking astronomical observations. Those who attend these Unarian schools are akin to students pursuing undergraduate education in our world, . The Decenarian maths have a deeper focus on long-term problems, perhaps akin to advanced graduated students and early-career faculty. Erasmus, the protagonist, belongs to one of these maths, and he and his fellow Decenarians do astronomical observations and analysis, even more detailed literature reviews, and other activities that feel similar to those of graduate school in real-world universities. Different maths can study the same topics. Erasmus's Decenarian math contemplates the "polycosmic" nature of a multiverse—a key topic of the book—which is also studied in Centenarian and Millenarian maths.

The Centenarian and Millenarian maths are said to have a deeper research focus on longer-term problems, but the specifics are not fully explained; the Millenarian math, especially, becomes a bit more fantastical than real-life science. Sometimes the long-term focus of the maths can go awry. For instance, there is a phrase, to "go hundred", (229, which describes when Centenarian maths open only to reveal that everyone has either gone insane, disappeared, or is dead—apparently driven mad by their isolation.

The only Millenarian character in the book is Fraa Jad ("Fraa" is a title akin to "Friar" or "Brother"), whose intellectual prowess and ability to see across multiple worlds is described as immensely powerful and becomes essential to the plot of the book. Some avout who live in the Millenarian maths are revealed to have longer lifespans, achieved perhaps through a type of research and self-reflection.[20] This longevity surely enables much longer-term study and focus, but it doesn't illuminate what it means to have thousand-year research projects. There are other ways in which the Millenarian maths are supernatural: the protagonists discuss a centuries-old appearance of a mythical creature's body[21] inside a parking structure, for example, is attributed to the transformative abilities of Millenarian scholars. The fear of such power by the Saecular world was then cited as a reason for a "sack," or the takeover and reform of the maths by the outside world.

Thousands of Years of Science-Induced Civilizational Rise—and Collapse

The timeline of the *Anathem* universe is fascinating for how it portrays the relation between science and society. The timeline suggests that the story might be approximately 3,700 years in the future, and the book makes various oblique hints that the world of Arbre is more technologically advanced than our own.[22] Our current era would align with the end of what the book calls the "Praxic Age," which corresponds to a period beginning with the Industrial Revolution. (297, 328, 372) While the Praxic Age had great technological advancements, the world of Arbre had several technology-induced calamities that ultimately led to civilizational destruction and collapse.[23]

Arbre society then underwent a period of reformation known as the Reconstitution, which redefined the relationship between science and society by instituting the separation between maths and the Saecular world described above. The Reconstitution was so important to Arbre society that they remade their calendar year to be year 0 in the mathic timeline. However, the science-society relationship continued to evolve significantly in the millennia before Anathem's plot begins. Even with the maths separated from society, new technologies continued to emerge from them that disrupted Saecular society, leading the Saecular world to sack the mathic world and impose new regulations. Each sack resulted in changes to the science-society relationship. The sacks included[24]:

First Sack

Technological cause: The avout create "new matter," materials with atoms possessing slightly different atomic masses and emitting different wavelengths of light, causing the

laws of physics to function differently. New matter enables the creation of revolutionary artifacts and tools of incredible strength and lightness, but it disrupts society, leading to the First Sack.

Change in Science-Society Relation: New matter's use is heavily regulated, with the Saecular world controlling new matter production only in limited facilities outside of the math.[25] A mathic entity known as the Inquisition is established to monitor compliance with these regulations.

Second Sack

Technological Cause: Maths begin engaging in gene-sequencing work, or what Erasmus refers to as "syndev," apparently a portmanteau of "synthetic developments." While not explicitly described in the story, this research evidently leads to the creation of potentially dangerous life forms or diseases that disrupt society.

Change in Science-Society Relation: After this event, additional rules are imposed on the maths, ensuring stricter oversight of their activities and removing any significant research infrastructure outside of astronomical observatory tools.

Third Sack

Technological Cause: Some Millenarians, who became known as Incanters (seemingly akin to wizards (53, 69)), develop the ability to create matter—even without scientific infrastructure and research equipment. The Saecular world becomes dismayed when a previously non-existent dinosaur mysteriously appears, fused into a construction site.[26]

Change in Science-Society Relation: Incanters seemingly stopped existing, though the exact change in science-society relations underlying this is unclear in the book. The backstory raises questions about whether some of the inciting research still continued to occur—after all, it's hard to regulate or prevent people from merely thinking—though the plot of the book does eventually provide more details.[27] Three of the oldest Millenarian maths (the so-called Inviolate maths, which were never sacked) that had maintained nuclear waste continued to exist. The book implies that these reforms were enforced after the Sack, though it also hints that an external group was allowed to form outside the maths that pursued research about Platonic ideals. This group's research focus on the multiverse sets the stage for the book's climactic events.

Aspects of the Society-Science Relationship in *Anathem*

The timeline of the mathic world shows a complex relationship between the maths and the Saecular world. This section highlights a few other features of the science-society relationship. They illustrate the thoughtfulness that Stephenson put into his work—but they also raise questions about how separately science and society might be made to act given the long-term perspectives.

Service to Society in the History of the Maths

The maths have come together in the past to help humanity defend against an external threat. When such threats emerge, a "convox" is summoned bringing together leaders across the mathic world. One past convox is described as occurring when an asteroid was projected to impact and likely destroy life on Arbre. (95) The avout worked with the Saecular world to design a spaceship that would travel to the asteroid and deflect it. When it later emerged that the asteroid would narrowly miss the planet, the deflection mission then became a research mission. But the ability and precedent to draw upon the avout to solve problems was a clear sign.

Another such convox occurs as a key plot point in the book, in response to dealing with an external invasion. An interesting nuance in the science-society relationship emerges when the book discusses the views of the Saecular leaders who attend the convox and are trying to understand the avout's deliberations. It's mentioned that many in the Saecular world have had concerns on whether the massive amount of resources spent on the avout's convox were worth it.[28]

"Big Science" vs. "Decentralized Science"—and How Efforts to Regulate Science Seem to Fail

The cyclical history of the maths, where regulations follow excesses of scientific and technological progress, ties well to real-world discussions about "big science" versus "decentralized science." Much scientific research takes place in huge, infrastructure-intensive facilities, such as the European Large Hadron Collider or the US National Laboratories. In *Anathem*, the Saecular world's regulation of the maths increasingly deprives the avout of access to that kind of major experimental infrastructure, leaving them with little more than their own intellectual capabilities and ability to observe the cosmos.[29]

Despite being forced to do a form of decentralized science, the avout manage to conduct incredible research through rigorous dedication to their work. The moral for real-world scientific and engineering progress is ambiguous, especially as the progress that occurs in the book takes thousands of years. Most scientific leaders would assume that scientific progress could not occur under *Anathem*'s restrictions against infrastructure and continuous information sharing, but there are likely some areas of real-world research that could be aided by the long-term discipline of the maths.

Reframing the Science and Society Relationship

Science Saves the World and Becomes Coequal with the Saecular World

The *Anathem* plot ultimately leads to a reframing of the social contract for science of the world of Arbre, where the avout are no longer sequestered into a separate world of mathic settlements. This happens after a Millenarian uses the benefits of deep research on the nature of worlds in order to end a major invading threat to civilization (which I'll only discuss in footnotes to avoid spoilers).[30] The ending establishes two distinct but equal "Magisteria" or authorities on the planet Arbre, with one Magisterium being leaders of the Saecular world and the other being the leaders

of the avout. As a character says at the end, "'Behold.… There are two Arbarns on that vessel, of coqeual dignity. Such a state of affairs has not existed since the golden age of Ethras. The walls of Tredegarh [a mathic concent] have been brought down. The avout has escaped from their prisons. Ita, a group previously segregated from avout to focus on information technology] mingle and work by their sides" (942). Such language by an avout-related scholar shows the perceived depth of the reordering of the science and society relationship, with science moving from a subordinate to an equal position.

However, the book ends before it describes how the new science and society relationship will emerge in the reconstituted world. The protagonist, Fraa Erasmus, plays a critical role in setting up what the new world will look like. The epilogue describes him setting up a new settlement in honor of Saunt Orolo (with the honorific being the book's form of "Saint"). In the reconstitution, Erasmus states that avout and non-avout would be able to enter and leave the maths at will, and that families can be close to those inside the maths. All of the avout could now socialize at the same bar, marry, and regularly share ideas, both across maths and with the Saecular world.[31] The protagonists seem blissfully unconcerned about the rapid reconfiguring of how science and society relate in their world. They are perhaps a bit like practicing scientists and engineers who like to just do their work.

The protagonists in the epilogue do mention thinking ahead about the need to defend themselves several centuries into the future.[32] It seems likely that many restrictions on technologies such as new matter will remain; as the avout continue their work in this new world, Saecular leaders may even need to create new restrictions. I'll leave major spoolers to a footnote, but the avout do also partner with the saecular work on a massive science and exploration project, committing to sending out their own space ark into the universe, on a mission vastly more complex than the Apollo program.[33] There is little discussion about who will fund such exploration, much less the livelihoods of the maths or of the new settlement that Erasmus is establishing, especially if the maths are allowed to create expensive new research infrastructure again.[34] It does seem implied that the Saecular world will more directly fund some of this work, especially the work to increase activities in space, since otherwise such an a space ark exploration effort would be difficult to implement.

Considering Anathem's "Final" Science and Society Relationship

What then should we make of the central social structure of *Anathem*—the maths, partitioned by time and divided from society, strictly regulated by government, and yet enabling regulated and beneficial progress? The tensions produced by these forms of separation—physical, temporal, disciplinary—simmer throughout the book, having shaped the governance of the avout to regulate risk to society but also ensure some focus on long-term thinking. While the world of *Anathem* takes the idea to an extreme, its subdivision and regulation of science resonates with real-world issues today.

What does this ending really mean about the book's revision to the science-society relationship? When I first reviewed the book in 2011, I interpreted Stephenson's move as a plea to elevate the status of science and remove restrictions placed on science. It seemed to me that the book embodied Polanyi's Republic of Science. By the end of *Anathem*, the limits imposed on the avout are gone, especially as the powerful Centenarians and Millenarians can share their insights outside the math (and with each other) at any time. This is a major reversal to the worldbuilding backstory leading up to the events of *Anathem*.

There have been comparable debates in the real world about the status and governance of science. Prior to World War II, US federal funding for science was minimal, with private foundations leading the way. As the country emerged from the war, the sense that scientists and engineers helped to win it through military systems and the atomic bomb was pervasive. Many science policy histories recount how the then-US science policy advisor Vannevar Bush published *Science: The Endless Frontier*, which emphasized the importance of long-term, curiosity-driven research that operates largely independently of societal pressures, but is still supported by the government. Such research was projected to always provide future benefits to the US national interest. Bush himself also advocated for the (eventually successful) creation of the National Science Foundation (NSF).

This marked one of the highest profile debates in US history about who should control funding for science—presidentially appointed political appointees or scientific experts chosen by their peers. A compromise was eventually reached, in which the president appointed the head of NSF but the management of the agency was shaped by well-respected scientific leaders, giving some measure of autonomy.[35]

Anathem's "coequal" level of scientific autonomy is an extreme—akin to making scientific leaders equal to democratically elected ones, and putting them far above leaders in other areas of society, such as religion, entertainment, or culture.[36] This is a status never (openly) dreamed of in real-world science policy frameworks.

Is the Second Magisterium for Science Really a Militaristic Ploy?

On my 2024 rereading of Anathem, I paid closer attention to Emman, the young secular military leader who befriends Erasmus.[37] When Emman introduces the concept of the two Magisteria, comprising the separate leadership of the scientific world and the Saecular world, he notes how societal restrictions against the avout doing research contributed to the planet's insufficient scientific and engineering resources to respond to invaders. After recounting the history of societal restrictions on the maths, Emman says:

> Turned out that all we'd been doing was losing the arms race to cosmi that hadn't imposed any such limits on their avout. And guess what? When Arbre decided to fight back a little, who delivered the counterpunch? Our military? The Sæcular Power? Nope. You guys in the bolts and chords [the dress of the avout]. So the Antiswarm [avout community] has

> garnered a lot of clout just by doing a lot and saying very little. Hence the concept of the two Magisteria…(933)

Emman describes Arbre as being in an arms race with worlds in other dimensions and stresses the importance of ensuring they do not overly restrain themselves. He emphasizes how much the avout were able to achieve during the crisis that saved the world, and how they did so with humility and seemingly low levels of support. (It is perhaps hard to imagine leading scientists and engineers in our world being willing to so prominently help society while "saying very little.") Further, the two Magisteria decide to partner on sending an ark to explore other worlds, which is an ambitious project with scientific and potential military implications.

Given this, my interpretation from 2011—that the book was advocating an unfettered embrace of science—doesn't seem aligned with Stephenson's actual intent. A more nuanced reading might suggest that the creation of the coequal Magisteria was partly to ensure unfettered research while addressing a very real threat. This ties into a long-standing debate about the extent to which military policy and geopolitics drive science policy decisions—and whether that is appropriate.

If the primary reason for establishing the community of maths as a coequal Magisteria is the protection offered to the rest of Arbre by the Millenarians, then this is not a permanent framework for how science and society should interact. It is an end-state for how science and society should interact in a moment of prolonged military crisis—something like the Cold War.[38] It also raises questions about what we should do without the threat of some impending conflict. The once-in-a-lifetime threat of invasion does seem like it might be a uniquely crystallizing force that would unify politics. Could such a unification continue to last for decades—much less thousands of years?

Conclusion: Alternative Science-Society Simulations Suggested by the *Anathem* Plot

Stephenson's Saecular world appears to have embraced a Cold War framing to motivate future scientific research. Such a reading is relevant to our world today. Given that Stephenson's book looks at a future civilization across thousands of years, and given his savviness about the history of real-world innovation policy, it is humbling to consider that his primary rationale for the long-term support of science might be based on a military rationale such as the Cold War, though cultural and scientific desires are also embodied in the space ark project. However, despite this militaristic conclusion, the history of Arbre's regulation of science and engineering connects with contemporary efforts to acknowledge and explore the ethical and societal considerations and impacts of science.

What would have happened if science had not become a coequal Magisterium? This offers a fascinating chance to informally simulate an alternate outcome for Anathem, supposing that world were no longer subject to a military threat. Other rationale for greater liberation of the avout could have been prioritized, such as the inherent desire for knowledge, the desire to create better quality of life on Arbre, or the broader exploration of the Arbrean universe.[39] One could imagine taking

any of those rationales, and then exploring how that desire and rationale for continued Saecular support of the mathic world would change over time? How would that relationship evolve over the course of thousands of years? It's a thought experiment worth consideration.

The recurring focus on the long-term future of humanity in Stephenson's work—to prevent its fall and to focus longer term research among the Centenarians and Millenarians—does hint at a belief about progress in technology that can arise when enough research and attention is focused on a topic.[40] This aligns with Stephenson's work on Project Hieroglyph, in which he authored a story about creating a 10km-tall space launch tower on Earth, focusing on the myriad of policy, management, and cultural challenges that needed to be overcome to build such a tower (see his paper in Finn and Wylie 2014. There is a strange tension Anathem about whether progress on 1,000 year–level problems is achievable without significant spending on centralized scientific infrastructure, which the book's epilogue does not hint at.[41]

The brilliance of Stephenson's novel lies in its exploration of long-term thinking and deep research problems framed in the context of a continuously strained and risk-laden relationship between science and society. These tensions are clearly shaping how science is organized and managed in *Anathem*, which is in turn shaped by the history and culture perceptions of the avout. While the book is most famous for its reconstruction of Western philosophy, it is also perhaps one of the most interesting simulation tools for imagining different approaches to science policy than the ones implemented today.

Notes

1. The work for this paper was performed in a personal capacity. Opinions expressed in this paper reflect the views of the author and do not necessarily reflect NASA or the United States Government. I am also grateful for a draft review of this by Jonathan P. Lewis, Michael Bernstein, Ryan Faith and for past collaboration with Tind Shepper Ryen. I am deeply grateful for many thoughtful comments and suggestions by Jay Lloyd that greatly improved the paper.

2. I am largely writing for a US federal science policy context, recognizing that there are many similarities and differences across countries.

3. Funding from "society" can occur directly through grants, agreements and contracts with federal agencies, or there is a large degree of private sector funding and acquisition, much of which can also indirectly supported by federal tax breaks or investments.

4. Such a social contract is often implicit, and rarely formally written out in a formal agreement by representatives of science and society. However, much of the legislation supporting science in the United States is framed by legislation passed after consulting scientific leaders. The research goals of such legislation then get translated down into specific funding calls that describe what work should be done, and that scientists then propose to do.

5. There's a broad range of science policy research that explores facets of these topics. Kitcher 2001 highlights how social processes can shape what is deemed to be scientifically significant or not. Bozeman and Sarewitz 2011 provide a framework for doing case studies on how science leads to societal outcomes. Pirtle 2019 discusses history and challenges that have arisen from efforts to track the benefits of R&D in a specific industrial context. There's increasingly more research about the role of hype in the rhetoric used to advocate for funding of new projects (Roßmann 2021), which makes it more challenging to ascertain real benefits.

6. Per Guston 2023, "Section 10343 of the act, entitled "Research Ethics," mandates that NSF engage with the "ethical and societal considerations" of the research it funds. It conveys "the sense of Congress" that "emerging areas of research have potential ethical, social, security and safety implications that might be apparent as early as the basic research stage.… [The incorporation of such considerations] into the research design and review process for Federal awards, may help mitigate potential harms before they happen."

7. One could explore publications in the Journal of Responsible Innovation, IEEE Technology and Society, or work in the Issues in Science and Technology journal for examples of considering societal impact more deeply. For work on achieving greater innovation success in the long term, Research Policy and IEEE Transactions on Engineering Management have more resources.

8. Gordon 2017 explores long-term changes in US innovation growth and recent efforts at understanding "progress studies" touch on the issues. However, a discussion of the very long term doesn't occur in much of the science and society literature, such as Guston's work above. This may be understandable, due to the priority of paving new paths in the here-and-now, but it does reflect opportunities for using science fiction to explore what an ideal future state might be.

9. Sarewitz 2007 discusses one set of calls to double the budget of the US National Institutes of Health, but he then provides historical context: in almost all cases the research and development budget of the US government merely increases at the same rate as inflation. NAS 2007 also represents a similar call.

10. There is a long-standing tradition of using philosophical thought experiments—such as Plato's Republic—to envision what an ideal society might look like. John Rawls and Philip Kitcher's work, especially the latter's *Science, Truth, and Democracy*, are in this vein. Building on this tradition, some recent efforts have applied similar thought experiments to science itself, asking what an ideal scientific enterprise should entail and what kind of science ought to be prioritized. These explorations challenge us to rethink the societal role of science and to consider how its goals, methods, and outcomes might better align with public needs and values.

11. For this research paper, I will reference the Kindle edition for consistency in page numbers.

12. Others have mentioned possible connections between Stephenson's Anathem and Walter Miller's *A Canticle for Leibowitz*, which looks at a religious monastery as thousands of years go by after the fall of civilization. I've not done enough research to know how or to what extent Stephenson viewed that book as an influence – it does not appear in his acknowledgments.

13. Asimov's Foundation is another example of a group of separated scientists who think deeply on their societal impact and receive pushback from broader societal groups.

14. Stephenson has made numerous comments about innovation policy in other contexts, emphasizing the need for greater societal focus on innovation. Notably, he participated in a debate in 2010 with Arizona State University President Michael Crow, discussing whether science fiction authors were doing enough to inspire society to tackle pressing challenges. This debate took place shortly after the publication of *Anathem*. and led to Stephenson partnering in ASU's Project Hieroglyph project to write science fiction that could inspire a more ambitious future. Stephenson has also served as an advisor to the aerospace company Blue Origin, including during the time when Anathem was likely written. His social connections to influential thinkers such as Danny Hillis and Stuart Brand—both of whom are prominent in Silicon Valley—may have inspired the depiction of the ITA (Information Technology Administrators) in the book.

15. The avout are prohibited from having children and from maintaining regular contact with family or loved ones outside the maths. They live under the potential fear that the saecular world might decide to invade. Perhaps these exaggerations reflect some of the views and real-world sacrifices that scientists and engineers have or make, where it's often seen that a life dedicated to research comes at a cost of family and personal connections, with funding support from the state being difficult but attainable. The avout have to also follow rules that are more mundane, such as being forbidden from drugs that can change the state of the mind, to needing to follow rituals of prayer and community behavior, and more.

16. There is also a fascinating discussion about "iconographies"—the study of the ways in which the avout are perceived by those in the outside world. (71). Some observers describe the avout as creators of risks that could run amok, hoarders of hiddn secrets, or as silly and irrelevant figures. These perceptions significantly influence the perceived and potential value the avout might bring to society, and the young protagonists are taught to identify how those in the outside world are perceiving them based on these narratives.

17. The one exception to this is that a religious zealot, the Warden of Heaven, is portrayed as a disruptive leader, whose political clout is so advanced such that he is the first one to be sent over to meet a major invading threat (483). A minor spoiler: His comical death in the book (893) takes on further meaning when the subsequent saecular leaders seem to be much more akin to technocratic or military leaders on Earth.

18. My colleague Martin Stacey shared with me his reading that the world of Arbre doesn't appear to have deep inequities, and we may have more insight into the broader politics of the

saecular world than one might suppose. I'm uncertain, as we only see very limited glimpses of the world, and the world we see still has dire events, such as smugglers taking people across borders.

19. The book briefly teases (without explanation) that there are "pinprick maths" outside the walls of concents, consisting of rooms in the saecular world where an avout sits and tirelessly performs research. (168)

20. Others interpreted Jad's longevity as tied to his proximity as a thatcher to protect the nuclear waste on Arbre.

21. 469; the writing makes it unclear if it was a dinosaur or an actual dragon.

22. While there are occasional advanced technologies, such as a "new matter"-based, highly versatile spacesuit that can operate in space for seemingly weeks, my colleague Ryan Faith noted that most of the technology described in the book seems very familiar to people on Earth. This offers another way in which the book is deliberately an exploration of a "long now."

23. The book hints that climate catastrophes and wars occurred but states that the key details were lost (see the glossary entry on "Terrible Times"). The book states that nuclear waste was stored—and remained potentially reconstituable for use in weapons—in a few of the Millenarian maths, which becomes a minor plot point in the book. The history and rationale for this sequestration is never fully explicated. One might suppose they were kept in the maths to ensure that the waste and weapons could be maintained by experts, and perhaps as a play by the maths to maintain some power over the saecular world?

24. The best and most concise summary of the timeline for these sacks is described in a late discussion between Emman and Fraa Erasmus (933–935). The glossary also provides some definitions.

25. Somehow, the Saecular world is assumed to have regulated itself (!) and its use of new matter, though this is not explored.

26. A mild spoiler: The "polycosmic" or multiverse-like nature of reality led the Millenarians to develop the ability to tie into multiple timelines of the universe. This becomes pivotal to the final plot resolution, as the Millenarian Fraa Jad helps ensure the success of the protagonist's mission across many dire challenges.

27. Another mild spoiler: The book eventually reveals the existence of the Lineage, a group focused on understanding the nature of reality and how ideal forms may propagate across different strands of a multiverse. The conclusion (934, 942) suggests that the Saecular world had enabled the Lineage to operate both within and without maths, and that there had been a secret agreement that the Lineage and its members in maths would help in times of great need. Fraa Jad was secretly given a key detonation device by the Saeculars (as said by the character Emman, 935) which suggests such a partnership.

28. For another discussion on the cost, see 297.

29. One particularly fascinating aspect is the continued use of astronomical observation. While the avout lack access to advanced laboratories or experimental tools, they still engage in the study of the cosmos as a way to test and refine their theories. This reliance on celestial phenomena underscores the resourcefulness of the avout and highlights the enduring importance of astronomy as a discipline that requires minimal infrastructure while addressing profound questions about the universe.

30. A plot spoiler: Given that the mathic theories about alternate universes is shown to be true when an invading alien spaceship seeks to conquer Arbre, there was deep uncertainty about whether the Arbrean Saecular world and the mathic world could combine forces to stop the threat. The young protagonists and a mix of older avout, including the Millenarian Fraa Jad become part of a last-ditch attempt to board the invading space ark and find a peaceful resolution. They seem to stay continually on the brink of disaster and keep moving forward to finally reach the space station, though the crew members have dreams that some among their number had been killed, including Fraa Jad. Eventually they make it to the alien space ark, board it, and face challenges adapting to the atmosphere. Fraa Jad and the Fraa Erasmus at one point awaken together, and Jad reveals that he is able to extend his mind into multiple branching worlds stretching out from their initial mission. While some crew members had died in some of those scenarios, he was able to seemingly blur those worlds together to keep the crew there alive. He then guides Fraa Erasmus on several sorties, including a visit to meet with the leader of the invading army. Fraa Jad then seemingly resets the timeline, but the invaders themselves have nightmares about Jad's ability to shape, and they began to deeply fear the Millenarians. The book describes Jad's abilities as a form of praxis (technology) that is a result of his group's dedicated research. As such, it is research that is described as having saved the day. See footnote [currently 26] for slightly more information.

31. Would such intermingling undermine the ability of the Millenarian maths to have their deep long-term focus? I think likely so, but, as noted elsewhere, it's hard to imagine what the Millenarian research framing problem really is.

32. Indeed, as Jonathan Lewis reminded me while reading this draft, Fraa Erasmus and his team were designing in placeholders for gun mounts into their new Concent of Saunt Orolo, preparing for times hundreds of years in the future when the math may need to defend itself. It raises interesting questions about what a steady state balance between science and society might look like.

33. Following up on other spoiler footnotes: after the invasion of humans from alternate versions of Arbre, several of the alien visitors wish to continue to explore into future dimensions, and some from Arbre seek to join them. They hope to explore if the next universe they visit will be sufficiently advanced such that they can gain insight on what caused the events of Anathem to take place. Such an expensive mission is admitted in the book to be a massive undertaking but also potentially one needed for defense against future interdimensional interlopers who might

come to attack Arbe. The rationale for the ark mission is thus a mix of cultural desires (to continue exploring the multi-verse), scientific desires, and security/defense desires.

34. I think the epilogue is silent on whether any future restrictions against the maths having powerful scientific and engineering infrastructure would continue. The new site Erasmus and Arsibalt are constructing has a workshop but no seeming scaling for a large scientific manufacturing site or the like.

35. Significant debates occurred between Bush and Senator Harley Kilgore about to what extent the political leadership of NSF needed to be appointed by the president. Bush opposed such an approach, but Kilgore won out in getting a politically appointed leader from the president, rather than letting scientists decide.

36. While I and others often refer to the avout as scientist monks, highlighting the religious similarities between the avout and real-world religious monks, it should be noted that religious groups exist in *Anathem* separate from the avout, such as the Christian-seeming Ark of Baz. While the avout's dedication may perhaps be religious in nature, they exist separate from religious groups, and as such organized religion is effectively excluded from the book's concluding dual Magisteria.

37. Emman also provides some of the clearest dialogue about the historical back-and-forth between the mathic world and the Saecular authorities, which is the basis for my timeline discussion above. He seems like a reliable source for understanding why the Saecular world created the coequal Magisteria.

38. Continuing the spoiler footnotes: the resolution of this 'Cold War' in Arbre might also not conclude on any short time-horizon, as the lingering threat of additional inter-dimensional visitors might not occur for thousands of years. As for sending of a space ark to explore other cosmi, the book only lightly develops the rationale for doing so in its prose, and it's not a focus of the protagonists in the epilog who go about setting up a new Math. Perhaps it is akin to the world taking on the most ambitious possible scientific project, transcending a military context, though it is seemingly still undertaken in the context of knowing whether other cosmi might pose a threat to Arbre.

39. The decision to partner on exploring a new ark to the multiverse is perhaps fairly similar to this vision for space exploration. This also oddly maps with the series finale of the *Star Trek: Lower Decks* TV show in 2024, which has a group of Starfleet move from exploring new parts of our universe to explore alternative ones.

40. The book implicitly focuses on physics—and a deep focus on its 1,000-year problems—to the partial exclusion of other areas of science such as biology or the social sciences. It would be interesting to imagine what the plot of the book might be if another area of science took to the fore. There are also interesting questions about how knowledge and technology get exchanged at the 1/10/100/1,000-year exchange periods of the maths, which the book does not detail.

41. The plan to build a space ark and continue to find more advanced realms may bely that thought. That would be a massive infrastructure project without parallel in our world.

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