Openness in Science and Technology

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Sam Buxbaum

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

Advisor

Joshua Earle, Department of Engineering and Society

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Introduction

Openness in science and technology is critical for the development of new ideas and for the long-term prosperity of humanity. Openness refers to the transparency of information, data, and methods in the development of scientific discoveries and technologies. Progress occurs when new ideas can build on the success of previous ideas. When scientific and technological information is shared freely and openly, there is a broader base of previous ideas to draw from, and progress accelerates. This is the central idea of the open science and open source movements.

Openness in the scientific process dates back to the beginning of the scientific revolution with the publication of the first scientific journal, *Philosophical Transactions of the Royal Society* (Singleton, 2014). The open sharing of scientific ideas for the purpose of rigorous testing and verification starkly contrasted the dominant practices of scientists at the time, but it provided the fuel necessary for the scientific revolution to take off (David, 2008). The advances in human society over the past few centuries can be credited in large part to the cultural change brought about by this shift in attitude.

More recently, humanity has undergone another revolution with respect to the way information is shared. The last few decades have seen the development of the internet from a file sharing experiment to a ubiquitous network containing all of humanity's collective knowledge, allowing information to be disseminated at a speed and scale never seen before ("A Brief History of the Internet"). The open sharing of information has grown from a scientific interest to one of the foundations of modern life.

The rise of open source software has accompanied the acceleration of information exchange. Open source software is software where the source code is publicly available for inspection and modification. Though it is not the most financially successful type of software, open source software is the foundation from which the rest of the software industry builds (Towers-Clark, 2019). For example, the most famous open source project is the Linux kernel, an operating system which runs the vast majority of internet servers and on which almost every major technology company depends (King, 2021).

Despite the benefits of openness, the technology industry as a whole depends on systems which enforce the protection of intellectual property. Through the patent system and the protection of proprietary information, innovators in science and technology are discouraged from openly sharing information in order to establish and maintain a monopoly over their narrow portion of the market. There are few open source companies and even fewer which find long-term success as a for-profit organization (Lord, 2022). Innovation and openness are each beneficial to society, but they are pitted against one another by current economic incentive structures.

The goal of this paper is to demonstrate the benefits of openness in science and technology and to show that openness can be prioritized without compromising other drivers of progress. Specifically, in this paper, we will show that the openness of a scientific or technological breakthrough enhances its impact on progress, that the open sharing of information and ideas serves the interests of the public, and that any incentives against openness are merely short term barriers resulting from failures of an economic system.

Methods

In order to discuss the pace of scientific and technological progress, we must first answer a critical question: *What is progress?* For the purposes of this paper, progress will refer to any contribution to science or technology which can be built upon by future work. That is, new developments must permit modification and improvement in some sense. As an extreme case, if a breakthrough technology is developed but kept completely secret from all except the inventor such that no future work can benefit from its existence, then it will not be considered technological progress in this scenario.

I will be analyzing open science and technology through the lens of actor network theory and the theory of the social construction of technology (Crawford, 2020; "Social Construction of Technology," 2020). Specifically, I argue that the systems and incentive structures in place influence the actions of individuals but are subject to change, and the actions of individuals in the development of science and technology impact the long-term trajectory of innovation. The paper follows in spirit from Daniel Sarewitz's book 'Frontiers of Illusion' (1996). Sarewitz argues that while the scientific process is a real and valuable method of discovery, scientific goals are not always well aligned with societal goals. The central point of the book "has nothing to do with what science is and everything to do with what science does and can do once it emerges from the laboratory" (Sarewitz, 1996, p. ix).

This paper is divided into three sections. The first section discusses the impact of openness on the pace of progress. The second section discusses the impact of openness on society more generally, arguing that openness serves the public interest. The first two sections neglect the motivation to make a scientific or technological contribution and assume that contributions will exist no matter what, where the only degree of freedom is the contribution's

openness or secrecy. This assumption makes it easier to reason about the effects of openness, but it is an inaccurate model of reality. The third section addresses this weakness by showing that incentives against openness are unnecessary and are merely the result of a poorly designed incentive structure.

Progress

Evaluating the sources of scientific progress is difficult because there is a necessary distinction between the progress created by individual developments and the progress brought about by a broader scientific and engineering culture, where a culture might encompass both a set of goals and values and an incentive structure for achieving them. There might be a discrepancy between the optimal degree of openness for an individual piece of technology and the optimal degree of openness for a technological culture. The United States, for example, does have such a discrepancy, a topic that will be discussed later. To begin, consider the specific case of the individual technological artifact, void of any connection to the culture or incentives that produced it.

I argue that an individual artifact's contribution to technological progress is directly proportional to its openness. More information provided freely to the public means there is more for future scientists and engineers to build on top of. This is demonstrated by the outsized contribution of minor discoveries and developments to broader progress, the role of open research as the foundation for private application, and the collaboration of corporations on open projects of broad interest but little commercial value.

A common argument is that science or technology deemed 'important' for the public, such as medicine, should be open, while less important science and technology can be

proprietary without negatively affecting the pace of progress. However, it is nearly impossible to judge the impact of a given technology or scientific discovery at the time of its development. Many of the most important breakthroughs are not appreciated until years or even decades after their announcement. In his essay 'The mismeasurement of science,' Michael Nielsen (2010), a famous computer scientist and physicist, states that "it's very, very difficult for even the best scientists to accurately assess the value of scientific discoveries. Science is filled with examples of major discoveries that were initially underappreciated." As an example, in a paper describing the probabilistic interpretation of quantum mechanics, Max Born added a footnote to a proof connecting the quantum mechanical wave function to the probability of observing a particle in a given state (Nielsen, 2010). What seemed to him like a mathematical detail only worthy of a footnote is now recognized as one of the most foundational ideas in quantum mechanics. Had he refrained from publishing the result due to its perceived unimportance, the study of quantum mechanics would have been delayed, and Born would not have been awarded a Nobel Prize for the discovery.

Additionally, small problems may seem irrelevant to the broader progress of a field, but all large problems ultimately decompose into a sequence of smaller ones. Even large problems that seem distinct frequently have a large overlap in their subproblems. Perhaps the best demonstration of the overlap is in programming and software development. Programmers have long been leaders in the push for openness, oftentimes without realizing it. There is a culture of code sharing for minor questions and bug fixes through forums and platforms such as Stack Overflow. A paper by Huang et. al. (2022) shows that slightly over six percent of code across the most popular Java projects is copied directly from Stack Overflow with zero or minimal modification. Interestingly, the percentage of reused code is increasing each year and is higher

for more experienced developers than junior developers. As the public database of solutions grows, developers have more past work to draw from, and they gain experience leveraging it to their advantage. The result is an efficiency boost to the entire field of software development.

The difference between the perceived importance or unimportance of a development is typically framed as the difference between fundamental research and application. It is widely accepted that fundamental research serves as the bedrock for all scientific and technological discovery. Maria Leptin (2023), president of the European Research Council, writes in an article for the World Economic Forum that fundamental research "establishes the essential foundation of knowledge needed to solve acute, practical problems." However, there is not a clean separation between fundamental and applied research. There is a large and growing body of work that spans the two categories. In 'When Ideas Are Not Free,' Murray and Stern (2007, p. 34) discuss such 'dual knowledge' and state that "most policy analysis assumes that science is an important *input* into the process of technological innovation," but there exists "the possibility that a *single* discovery can simultaneously serve as a scientific discovery and a technological innovation." In such cases, there is frequently a pressure or an incentive for researchers to patent the work. Patents are common in applied research, and their existence is typically justified by the belief that they prevent competition but not subsequent fundamental research. However, for dual knowledge which combines a fundamental insight with a practical application of the insight, the presence of a patent not only stunts competition, but also stunts further development on the theoretical foundation of the field (Murray & Stern, 2007). In fact, when dual knowledge works are both published and patented, they spark significantly less subsequent work compared to if they had been published but not patented, as measured by a diminished number of citations, a frequent metric for evaluating the impact of research. Blocking access to discoveries, regardless

of their perceived importance, slows the pace of progress across both theory and application in comparison with a more open culture.

Lastly, the presence and frequency of corporate collaborations demonstrates the power of openness to accelerate innovation and progress. Corporations are primarily motivated by profit, and they pursue profit by creating a competitive advantage over their peers. They typically attempt to prevent others from integrating or improving their intellectual property through secrecy or patents. However, corporations need to perform a variety of work to survive, only some of which contributes to their competitive advantage. When the development of a given technology does not contribute to their fundamental advantage over their competitors, corporations often form collaborative partnerships with said competitors. Hamel, Doz, and Prahalad (1989) of the Harvard Business Review remark that "the case for collaboration is stronger than ever. It takes so much money to develop new products and to penetrate new markets that few companies can go it alone in every situation." In such situations, the corporations' primary goal is to achieve technological progress rather than to develop and protect intellectual property. The collaborations represent the adoption of an open culture between the participating entities, even if the work is not made publicly available. In forming collaborations, corporations implicitly acknowledge that the open sharing of information accelerates progress, both by creating a broader and more diverse base of scientists and engineers and by eliminating redundant work among them, despite their individual incentives to avoid sharing information with a competitor. When progress is the primary goal, openness prevails.

Public Benefit

By itself, progress may not necessarily be the ultimate goal of a scientific and technological culture. A more important and directly related goal is the pursuit of a better society. Open information demonstrably accelerates progress, and progress is almost exclusively viewed positively. Free, unrestricted access to the latest technologies promotes societal wellbeing, as evidenced by recent government mandates on open access and corporate efforts to improve their public image through open source development.

A government's primary responsibility is to serve the public interest. When a government collects taxes from its constituents, there is an expectation that the tax money should ultimately benefit the constituents. In Vannevar Bush's 'Science: The Endless Frontier' (1945), which argued for a publicly funded research program that would become the National Science Foundation, he says, "Since health, well-being, and security are proper concerns of Government, scientific progress is, and must be, of vital interest to Government." Toward this goal, the Biden Administration recently mandated that all publicly funded research must be open access immediately after publication as a service to the American people funding the research, a strengthening of an earlier precedent (Marcum, 2022). The administration stated that the mandate is "building on the Biden-Harris Administration's efforts to advance policy that benefits all of America," and added that "All members of the American public should be able to take part in every part of the scientific enterprise." Proponents of open access scientific research have applauded the decision, claiming that the mandate will make scientific progress more expedient, equitable, and impactful. The announcement is a powerful acknowledgement that open access research is more valuable to the public than restricted access research.

Another resounding endorsement of the benefit of openness comes from the corporate world. At first glance, there would seem to be no reason for a technology company to praise the open source work of their own or of others. The widespread proliferation of open technology is a direct threat to companies attempting to establish and maintain a monopoly over a certain idea or product. For this reason, many companies have gone to considerable lengths to denigrate open technology and erode public confidence in it. In the height of his battle with the open source Linux operating system, former Microsoft CEO Steve Ballmer said that "Linux is a cancer that attaches itself in an intellectual property sense to everything it touches" (Greene, 2001). Given their legitimate competitive reason to disparage open technology, it may seem enigmatic that so many major corporations actively praise such work.

Corporations promote their work on open technology because the appearance of contributing to technological progress helps to increase their perceived value to society and thus their overall public perception. Many of the biggest technology companies, such as Meta, are losing the public relations game. Public trust in American technology companies is declining, with just fifty-four percent of Americans saying that they trust technology companies to behave ethically in 2022 (Froed, 2022). In response, companies boast of their contributions to society as an attempt at pacifying the public and justifying their own existence. In doing so, they speak of their contributions to open technology or open scientific research quite often. The front page of Meta AI's website speaks of both their open source tools for artificial intelligence and their open source research in artificial intelligence ("Meta AI," 2023). The same is true for Google's artificial intelligence division ("Google AI," 2023). This "open-washing" of technology is a subtle but cogent admission that openness better serves the public interest than secrecy, coming from those who have the most incentive to discredit and avoid openness.

Realigning Incentives

Ignoring the motivations and incentives that lead to the development of new ideas may make sense in certain scenarios, such as science or government funded development where the motivations are not strictly financial, but it is a poor assumption in general. The present state of technology and the technology industry is dependent on the existence of incentives to innovate. However, engineers' incentives do not frequently align with the idea of openness. In fact, there is currently a financial incentive directly against openness in America. Companies have an incentive to gain a competitive advantage through the creation of proprietary technology. Proprietary intellectual property and the patent system discourage openness but encourage innovation, resulting in a complicated effect on progress.

The patent system offers a mechanism through which an inventor of a novel technology can protect their invention from imitation, allowing them the exclusive right to capitalize on the new market that they have created. Today, almost all industrialized countries have some form of a patent system. Despite the potential economic and legal advantages to the creator, a protection on the proprietary intellectual property concerning a given invention offers almost no ability for others to build upon the work. However, it is worth noting that although the existence of a patent prevents further progress upon the idea from outside parties, it does make public some of the critical information about the invention. In comparison to a system with no intellectual property protection where those seeking a competitive advantage keep their knowledge secret, patents have the potential to increase openness. Publicly disclosing inventions increases openness if the invention is not likely to be independently replicated by another party. American courts have long held the public disclosing of ideas, even without a full design specification, as one of the primary justifications of the patent system (Eisenberg, 1989). However, in comparison to a

system which promotes openness and the free sharing of ideas, patents undeniably hinder openness. In total, a legal system which protects intellectual property promotes openness more than an anarchic system where only secrecy can generate a competitive advantage, but it falls far short of the ideal of an open culture of science and technology. A related idea is the notion of "copyleft," which allows work to be open and freely modifiable with the guarantee that all derivative works will have the same degree of openness and freedom ("What is Copyleft?"). In effect, copyleft protects against proprietary competition while creating a network of open projects which can share ideas. While copyleft solves one of the primary concerns about patents by providing a protection against the primary form of competition, it does little to encourage openness for those who did not already prioritize openness.

The intended purpose of the patent system is to create an incentive to innovate by promising a monopoly over the newly created market. In this sense, patents are quite effective, as the first mover in a new field has the guarantee of a lucrative reward. On a basic level, an incentive to innovate draws many people to work on potentially innovative ideas, and a large body of people creates a strong diversity of ideas, leading to progress. However, the protective component of a patent can artificially limit the ability of outside parties to further develop a technology. Tom Nicholas (2011) describes the process of technological development as consisting of leaders and followers, where leaders make the first progress in a given direction, and followers attempt to build on the initial success. Nicholas goes on to explain how the gap between leaders and followers can be beneficial or detrimental to progress, saying "If patents establish proprietary knowledge that inhibits the research and development (R&D) of followers, the gap is bad for growth. But it is good for growth if leaders get rewarded with patents and they are further encouraged to push out the technology frontier" (Nicholas, 2011, p. 791). Intellectual

property protection provides a strong initial incentive to innovate, but subsequent innovations by outside parties may be suppressed.

To summarize, patents have several positive and negative effects on scientific and technological progress, and their net effect on progress is complicated, to say the least. Though much effort has been devoted to determining if and in what circumstances the positive aspects outweigh the negative (Eisenberg, 1989; Merges & Nelson, 1994), the comparison is irrelevant. If a patent system's goal is to accelerate technological progress, its success in achieving the goal is ambiguous.

This raises the question - *is there a better way to accelerate progress?* In other words, the current dominant economic model places the goals of openness and innovation in competition with each other. Are openness and innovation inherently contradictory ideas, or is their disagreement merely a property of a faulty economic system?

The answer, it turns out, is that openness and innovation are not inherently competing ideas, but two sides of the same coin. Both promote progress, and openness enables maximal innovation, so we should attempt to create systems that emphasize both in tandem. Additionally, the current lack of an incentive for openness is not a *fundamental* barrier to openness. The barrier is a manifestation of certain existing economic policies, but such policies are malleable and not inherently necessary. Just as the government has the power to implement and modify economic policy and intellectual property rights, it has the power to further modify and fundamentally redesign them. The only roadblocks are political will and the development of a concrete course of action to enact the changes. If we can devise a method of accurately measuring an individual development's contribution to technological progress, then we can design an economic system

that properly compensates that contribution. An optimal economic system for scientific and technological progress would align the incentives of the individual with societal wellbeing.

Lastly, such fundamental changes are not only possible, but necessary. Scientific and technological progress *should* be a priority for any benevolent government. Broadly speaking, the purpose of the government is to serve the public. If certain behavior is recognized as yielding a public benefit, our incentive structure should promote that behavior.

Conclusion

The open science and open source movements encapsulate the dream of an open and collaborative scientific and technological culture that has been present since the dawn of the scientific revolution. Like all social movements, they ask us to question the assumptions that we have built our world around, in hopes of creating a more prosperous future. With recent global health crises and the looming threat of climate change, among others, there has never been a better time to fundamentally reevaluate our innovative processes. It is time for scientists and engineers to step up and answer the call. By establishing and embracing a more open innovative culture, we can unlock the full potential of scientific progress to create a better world.

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