



Is More Science Really Less Science? The Scientization of Science, 1900–2020

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Abstract

Sixty years ago, Derek de Solla Price’s influential *Little Science, Big Science* first documented that from 1900 scientific publications doubled every 10–15 years and then predicted that limited resources would end rapid progress leading to an imminent “scientific doomsday”—a strikingly false prediction given that contemporary global mega-science annually yields 3.5 million mainline STEMM journal research papers. Nevertheless, the idea of a coming crisis persists—supposedly current expansion is stagnating quality. Argued instead is that what was missed, then and now, is a worldwide deepening of *scientization*—the embedding of science as a core social institution, marked by expanded research capacity, diversification into new domains, and increasing specialization. Employing sociological insights about historical institutional development, Price’s empirics are extended to explain why STEMM productivity never plateaued. Fueled by a worldwide education revolution, universities enact three institutionalizing roles: *institutional entrepreneurs*; *main corporate units of research*; and a fiduciary of the *generalized symbolic medium* of papers. Illustrated by analyses from a recent bibliometric study of 3.3 million papers from 1900 to 2020, it is further suggested that instead of decline, through university-driven scientization the scale and capacity of science as a mature institution reshape the dynamics of discovery supporting sustained growth and quality.

Keywords Education revolution · Scientization · Collaboration dividend · Universities · Institutional theory · Sociology of science

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Growth and Crisis?

The 60th anniversary of Derek de Solla Price’s influential book *Little Science, Big Science* (1986 [1963]) provides a timely opportunity to revisit its intriguing combination of technical brilliance and an enduring, yet ultimately incorrect, prediction. Price was a pioneer in the bibliometric study of science, and with unique data for the time, provided by early science information entrepreneur Eugene Garfield, he was the first to demonstrate that by the 1960s, scientific publications had been growing exponentially for at least a century, doubling approximately every 10 to 15 years. He went on to predict that since logistic growth must eventually plateau, an inevitable “scientific doomsday” would arrive, marked by a decline in new discoveries and a shortage of high-quality science that could have economic consequences as dire as another Great Depression (Price 1986, p. 17). Both his empirics and prediction motivate the arguments here.

While Price’s sweeping empirical approach was groundbreaking, his prediction obviously has not come to pass. Each year continues to bring significantly more scientific articles, published across an ever-increasing number of journals reflecting expansion and differentiation of scientific topics. Far from being limited by constraints on growth, global mega-science flourishes, with annual output reaching over three and one half million new scientific articles—STEM and health/medical related papers (hereafter STEMM papers)—shown in Fig. 1 from only mainline journals excluding predatory outlets (Baker & Powell 2024; Dong et al. 2017). Unfortunately,

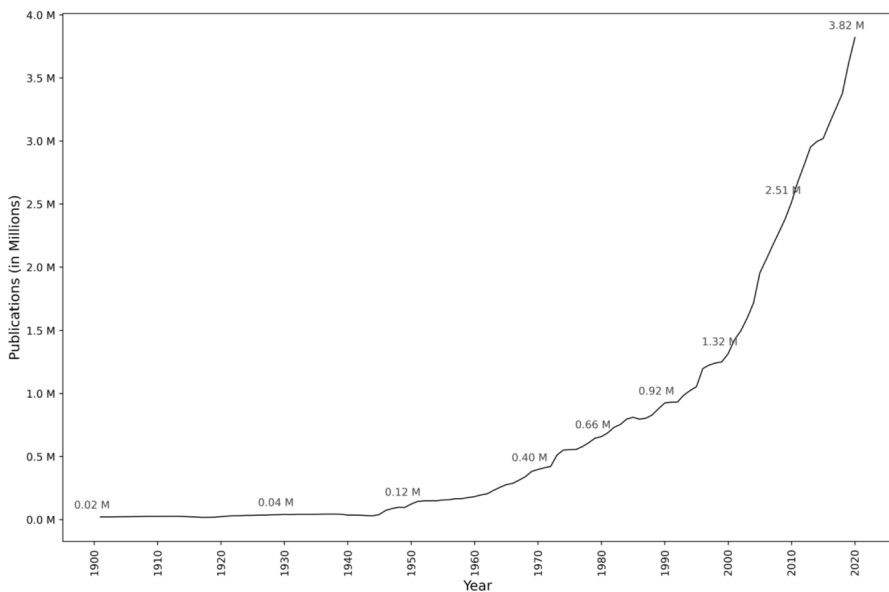


Fig. 1 Estimated Number of Annual STEM and Health-Medical Research Papers 1900–2020 Published in Mainstream Journals. *Source: SPHERE dataset, mainstream journals accounting for 95% of total citations and excluding predatory publishing outlets

Price's untimely death in 1983 meant he could not amend the faulty prediction in his otherwise important analytics.

In not anticipating the essential dynamics behind the worldwide institutional development of science, Price, however, was not alone. At the same time, the fields most suited to address this gap, the sociology and history of science, paid little attention to the bibliometric approach and Price's findings, overlooking their potential to indicate the scope of institutional development over significant periods and across different regions. Although early sociological analyses pioneered theories of science as a societal activity, social theory concerning institutions—including science—eventually stagnated (e.g., Ben-David & Sullivan 1975; Kuhn 1972; Latour 1987; Merton 1973; Sarton (2012 [1952])). The history of science remained wedded to specific periods, major discoveries, and individual scientists (Baker 2024). Both fields are therefore less well-equipped to explain the unprecedented long-term growth of science and its causes (Gauchat 2025).

Recent advances in institutional theory offer a more comprehensive explanation of the socio-historical development of the world's capacity for scientific discovery. New Institutional Theory (NIT) can frame the general history of global mega-science as the evolution of a successful societal institution (Abrutyn 2009). This process, increasingly known as “scientization,” refers to the historical growth of science as a societal institution, encompassing both the expansion of scientific inquiry into new domains and the increasing specialization within existing disciplines (Marques et al. 2025). Scientization is sometimes used only to describe the influence of scientific findings on non-scientific sectors of society—a behavior itself typical of a maturing institution and supported by empirical analyses (Drori et al. 2003; Schofer 2003; Schofer & Hironaka 2005; Schofer et al. 2021). In the context here, however, the term takes on a broader meaning of deepening institutionalization: The emerging autonomy of science's internal organization and the strategic actions of thousands of universities, other organizations, and contemporary scientists working globally to expand this institution (Baker & Powell 2024). By around 1900, global science began to reflect the early stages of an autonomous institution, predictably intensifying and differentiating from within, generating considerable and self-reinforcing legitimacy (Gauchat 2023).

As demonstrated below, scientization over the past century and a quarter is a classic example of institutional development, aided by a less-recognized, highly mutually beneficial relationship with the ascent of formal education to an institutional pillar of liberal society (Baker 2014; Meier 2009; Vanderstraeten 2015). Interpreted from the NIT perspective, a small group of innovative 19th-century universities acted as critical *institutional entrepreneurs* for science. Over time, universities worldwide also became the *main corporate units* of science and the key fiduciary of the institution's *generalized symbolic medium*—the peer-reviewed journal research article (or “paper” in academic parlance)—as a tangible indicator of the empirical search for knowledge revealing truths about this world (Turner 2010). This tripartite agency contributed to the accumulation of processes and resources encompassing scientization—and are necessary components of any foundational social institution of society—such as monopolization, legitimation, increased breadth and internal complexity, regulated conflict and competition dynamics, symbolic closure, and the use of symbolic media

in organizational dynamics (Abrutyn 2013b). While these three factors alone were not entirely sufficient, their *synergy* was essential in facilitating the growth of scientization over the past century and a quarter.

Despite the extensive and global institutional development of science, the notion of scientific decline intriguingly persists. Although Price's error regarding exponential growth in quantity has become obvious, some now argue that amid the cascading volume of publications a crisis of quality looms. Notwithstanding that research quality is notoriously difficult to define (e.g., Harris-Huermann et al. 2024), recent technically rigorous, large-scale bibliometric studies have been interpreted as evidence supposedly indicating that papers are becoming less "disruptive," that genuinely novel ideas are increasingly rare, and that content stagnation is affecting many scientific fields (e.g., Bloom et al. 2020; Chu & Evans 2021; Milojević 2021; Park et al. 2023). This leads to some envisioning a bloated and declining scientific enterprise, effectively reviving Price's original prediction of an impending crisis in science (e.g., Collison & Nielsen 2018; Landhuis 2016; Horgan 2018; Park et al. 2023).

The apparent paradox of simultaneous growth and stagnation raises a compelling question: How can an expanding population of scientists conducting more research on more topics in more locations result in a decline in scientific progress? We argue that there is, in fact, no paradox—science is not in decline, just the opposite. As with Price's original interpretation, many contemporary readings of bibliometric data neglect the unprecedented complexity and scale enabled by the symbiotic relationship between science and the global institutional transformations brought about by the maturing education revolution, particularly within universities (Baker & Powell 2024). This underappreciated trajectory of development helps explain why science continues to transcend expected limits to growth and supports an alternative perspective: the issue is not a crisis of quality or impact, but rather on-going evolution in the institutional and organizational dynamics of scientific discovery.

Combining Price's empirical approach with key sociological insights on institutional development expands on what *Little Science, Big Science* began over six decades ago. First, we frame the core ideas of NIT with examples of how the education revolution and its universities played three essential roles in the institutionalization of science. These claims are illustrated through evidence from a recent large-scale bibliometric study tracing the institutional dimensions of science from 1900 to 2020. Second, from the perspective of university-facilitated scientization, we argue that the scope and capacity of science as a mature social institution offer a plausible counterpoint to recent claims of a crisis of scientific quality.

Data and Method

The argument is illustrated by interpretation of recent published findings and new supplementary analyses of the Science Productivity, Higher Education, Research Development and the Knowledge Society dataset (SPHERE) (Powell, et al. 2017; Baker & Powell 2024). While bibliometric data have known limitations, peer-reviewed research articles remain the gold standard indicator of scientific activity and diffusion. Capturing representative global data on research papers dating back to 1900 posed a unique challenge. The SPHERE project compiled metadata on 3.3 mil-

lion research articles—using a weighted sample for years prior to 1970 and a full census thereafter—for the first and fifth year of each decade from 1900 to 2020. These articles were published in STEMM journals that the Web of Science (WoS) estimates to account for 95% of total citations (hereafter “mainstream STEMM journals”).

Metadata on content from all STEMM journals—titles, institutional affiliations, journal name, subject areas, and citation metrics—were acquired from Clarivate Analytics’ Web of Science. Because of high rates of incompleteness of crucial author affiliation and address in WoS indexed research papers from 1900 to 1970, the SPHERE multilingual team’s coded metadata from archived journals and supporting archived materials (e.g. faculty rosters at specific universities and research facilities) for a two-stage, random stratified sample of papers. The first stage, using the WoS list and categories of mainstream journals as a sampling frame, drew a stratified, random sample of STEMM journals, stratified by science, technology, health, and all other and by four main languages of scientific publishing (English, German, French, and Russian), particularly important in the first half of the 20th century before English became the dominant language of science. Sample sizes were increased by decade proportional to the increase in the frame of mainstream journals. Major general journals, such as *Nature* and *Science*, were always included in the sample, and extensive testing ensured the annual samples were representative (see Powell et al. 2017 for details).

In the second stage, a random sample of research papers was drawn from each sampled journal, and weights were calculated making sampled papers proportional to all research papers in mainstream journals of the selected year. The metadata from the weighted sample and the post-1970 full index were merged with annual global data on number and enrollment in universities. In calculating global publication totals, each research article was counted once, regardless of the number of authors and their affiliations. For cross-national estimates, a whole-count method was used: each distinct country among authors’ addresses received one count to its publication total.¹

By analyzing papers from journals indexed in the WoS Science Citation Index Expanded the empirical illustration presented here deliberately excludes the recent proliferation of “predatory journals,” which are typically omitted from curated databases due to insufficient editorial oversight and lack of rigorous peer-review processes. WoS applies strict selection criteria for inclusion, emphasizing consistent editorial quality, robust peer review, international author and editorial diversity, and demonstrated citation impact (Vanderstraeten 2025). As such, reputable open-access journals—such as *PLOS One* or *Nature Communications*—are included if they meet these standards. The arguments concerning the purported weakening of science addressed below primarily apply to mainstream journals and their publications. Alongside others, we acknowledge that journals with minimal quality control may contribute to a degree of hyperinflation in scientific publishing. Estimates of the scale of predatory publishing vary in rigor, but they consistently indicate substantial growth and a sizable output of articles (Beall 2012; Shen & Björk 2015). However, papers published in these outlets tend to receive significantly fewer citations

¹ See Powell et al. (2017) for assumptions and procedures on stratifying by language, sample sizes, and weighting, adding to the sampling frame in earlier years, and other details.

and have limited visibility within credible scientific communities, further justifying their exclusion from analyses (Frandsen 2017). Within the mainstream literature indexed in WoS, our findings—as well as those of others—show continued exponential growth in publication volume and stable citation patterns that reflect persistent scholarly influence.

New Institutional Theory and the University's Agency in Scientization

Social institutions function as cultural arenas in which innovation, consensus, and conflict shape legitimate visions of reality and allocate resources within specific sectors of activity. Compared to earlier institutional theories, NIT advances our understanding by emphasizing that the historical emergence of new institutions is a response to increasing cultural complexity—a process often described in sociological theory as social differentiation (Abrutyn 2013b; Turner 2010). Since classical institutional theory primarily focused on the functions and social construction of existing institutions, it lacked sufficient theoretical development concerning the processes underlying institutional change, including historical variation and the mechanisms driving such dynamics. Later, neo-institutional theory—distinct from contemporary NIT—addressed institutionalization processes, but offered limited insight into the creation, evolution, and agentic dimensions of emerging institutions (Meyer & Powell 2020).

Increased social differentiation brings both opportunities and challenges to social collectives. Some scholars have underscored its association with intra-group conflict, symbolic resource competition, and the rise of new status hierarchies (e.g., Bourdieu 1977; Iceland et al. 2023), while others have analyzed the broader structural and systemic consequences of differentiation (e.g., Luhmann 1995; Alexander and Colomy 1990). A core tenet of NIT is that the historical emergence and evolution of institutions hinge on varying degrees of institutional autonomy. Specifically, as differentiation intensifies, a new institution tends to form when a domain of meaning and activity deepens and becomes increasingly distinct from other institutional spheres (Abrutyn 2009; Colomy 1998). NIT further posits that the successful autonomizing institution depends on the above-mentioned tripartite agency of institutional entrepreneurs, main corporate units, and a generalized symbolic medium (and its control). These agentic roles will be examined in the context of the university's influence in advancing scientization and are summarized and compared to those evident in the institutionalization of law and the economy in Table 1.

Universities as Institutional Entrepreneurs of Science

Social institutions do not simply emerge. Drawing on the older sociological concept of charismatic carrier groups as “switchmen of history,” NIT hypothesizes that initiation and early progression toward autonomy require new actions—new ways of performing functions and related novel organizational forms—along with unique ideas that establish an initial monopoly over the legitimate authority to develop, apply, disseminate, and transmit new institutional practices (Abrutyn 2013b; Eisenstadt 1980). This process is driven by institutional entrepreneurs, individuals or collectives, in this

Table 1 Institutionalizing Agent Roles of Law, Economy, and Science

Social Institution Institutionalizing Roles:	Law	Economy	Science
Institutional Entrepreneurs	Rulers (proto)/ Jurists	Merchants (proto)/ Early Capitalists	Learned Clubs (proto)/ Specific 19 th C. Universities in Central Europe
Main Corporate Unit	State	Firm	University
Generalized Symbolic Medium	Decrees (proto)/ Constitution/ Legal Code/ Case Law	Money/Other Forms of Capital	Scientific Journal Articles (Papers)
Controller and Fiduciary (Trustee) of GMS	State	International Banking System	Professional Associations of Scientists (proto)/Universities

case universities fostering early scientization. Fin-de-siècle university entrepreneurs shifted the trajectory to a new institutional arrangement that partially monopolized and legitimized what became the norms, taboos, and patterned scripts for research, as well as the value systems surrounding and supporting it.

This early institutional development reinforced essential elements such as quality standards, ethics of discovery, recognized hierarchies of authority, accepted styles of interaction, language, and the adjudication of innovation. Together these form the shared *common cognitive framework* of science as an emerging institution (Luhmann 1995; Swidler 1986; Weber 1946). Nevertheless, its emergence was not a consensual, linear development, instead it unfolded through resistance, competition, inertia, and, occasionally, retrenchment. Ultimately, universities blended their educational and research missions, which increased the autonomy of both universities and scientific inquiry. Research activities became grafted onto the university structure, benefiting from these entrepreneurial institutions carving out “free cultural space” for the differentiation of physical, temporal, and symbolic resources (Colomy & Kretzmann 1995; Kosmützky & Krücken 2023; Musselin 2021).

Often historically referred to as the “nursery of modern research,” 19th century German-speaking universities—such as those in Berlin, Erlangen, Göttingen, Halle, Hanover, Heidelberg, and Leipzig—acted as crucial institutional entrepreneurs gradually developing a *university-science* model that integrated limited, but advanced, teaching with significant time and resources dedicated to scholarship and research (e.g. Clark 2006). Enacting this model, these universities established an early monopoly over shaping the common cognitive framework of science. Key organizational innovations included the development of the academic seminar, which collectivized research by bringing together experienced faculty-scientists and students to read, discuss, and critique ongoing scientific inquiries and theories. This approach served as an alternative to the traditional methods of lecturing and one-on-one tutoring. Additionally, these universities established early versions of independent departments, or

“institutes” in European universities, with teaching laboratories for astronomy, chemistry, mathematics, mechanics, physics, and technology. Another pivotal change was the diffusion of a “publish or perish” mentality, as universities gained academic freedom from state control in curriculum development and research. This was supported by the spread of the famed “Berlin system” of faculty development, a precursor to the global star system of faculty recruitment that prized and measured the quantity and quality of scientific output (vom Brocke 1999).

These characteristics were valorized by the loosely connected eponymic Humboldtian ideals of academic freedom, unity of teaching and research, broadest inquiry, and primacy of “pure” or basic universal knowledge (Ash 2006).² While this historical account is well-known, what is less appreciated is the extent to which early university entrepreneurship set the course for an expanding, robust and autonomous institution of science (Baker & Powell 2024). Two main points briefly illustrate this trajectory.

First, the ultimate proof of institutional entrepreneurship lies in the extent to which its initiated cultural arrangement takes hold and disseminates normatively. Since at least the 16th century, the earliest common cognitive framework for scientization—encompassing theory, systematic empirical observation, hypothesis testing, and publishing results—was already forming, aided by proto-entrepreneurial learned societies and royal science academies (Merton 1973). These organizations, eventually dominated by professors, bridged the movement of science’s framework into the 19th-century entrepreneurial universities (Stock et al. 2023b, a). Within less than a century the legitimation and initial monopoly of the university-science model rapidly spread. As shown in the first row of Table 2, by 1900, transcending local and national factors, 130 universities had faculty-scientists regularly contributing to research. These faculty members authored an estimated 30 to 50 percent of all STEM papers published in 92 mainstream journals, with the remainder contributed by independent laboratories, hospitals, firms, and unaffiliated scientists. These universities were supported by a growing postsecondary system of about half a million students, representing 0.2 percent of the world’s youth cohort in 1900, and were distributed across 26 countries in Northern and Western Europe, and including Russia, Canada, the U.S., Japan, and several others.

Further evidencing this shift is the geohistorical movement of the world’s “center of gravity” for scientific productivity. This center, which represents the weighted geographic centroid of countries’ total research output (1900–2010)—increasingly dominated by university-based scientists—closely follows the timing of educational development and the adoption of the entrepreneurial university-science model (Zhang, Powell & Baker 2015).³ In 1900, the world’s center of scientific production was in the middle of the Atlantic, reaching North America’s shore by 1940. Yet after WWII, the center moved steadily eastward as post-war European universities and sci-

² Despite their widely acknowledged centrality as guiding principles, detailed historical analysis shows a decoupled process as these ideals never represented a formally articulated organizational blueprint for universities in Germany or elsewhere, nor did they fully spring from their originator Wilhelm von Humboldt, nor were they part of one concisely derived model arising from a single university at a single point, such as is often assumed about the University of Berlin (Ash 2006).

³ Calculated with the SPHERE data as the global geographical center point, oceans included, based upon the sum of each country’s total publications by its scientists in ten-year steps from 1900 to 2010.

Table 2 Universities and Global Dimensions of Mega-Science and Expansion of the Postsecondary Education, 1900–2020.*

Dimension/Year	1900	1950	1980	2010	2020
1. Universities & other Postsecondary Organizations Publishing STEM Papers	130	260	7,270	38,200	41,000**
2. University-based Science (% STEM Papers with University Scientists)	30(50)***	55	66	85	90
3. Countries Publishing STEM Papers	26	36	162	206	220
4. STEM Mainstream Journals	92	486	3,902	8,337	9,500**
5. Worldwide Enrollment Rate: % Youth in Postsecondary Education	0.2	1.3	12.4	30	40
6. % Co-authored papers (% Internationally Collaborative Papers)	75 (0.3)	78 (1)	80 (2)	92 (22)	94 (26)

*Analyses of SPHERE dataset

**Approximately

***Because of missing and multiple author affiliations on papers in 1900, 30% is a conservative estimate. Detailed analysis reconstructing author information for a set of papers from Germany, the world's largest producer in 1900, and several other European countries finds a high of 70% of papers by scientists with at least an affiliation with a university, therefore 50% is a reasonable upper-bound estimate for the world

ence systems regained strength and balanced out North American discovery levels. By the 1970s, the center shifted southeast, reflecting the growing contributions of universities in prolific East Asian countries, with their concurrent sizable investments in higher education.

Second, the potential autonomy of a new institution is proportional to the degree to which it disrupts existing cultural arrangements, a factor that was significant in the case of the university-science model (Abrutyn 2013a). In the 18th century, Central Europe's universities were stagnant, trapped in a medieval model with diminishing societal relevance, hopelessly small enrollments, and rigid curricula grounded in ancient scholasticism (Clark 2006; Paulsen [2010] 1895; Watson 2010). These institutions were, in many ways, the last places one would imagine as sites of scientific research. The subsequent institutional disruption by a reforming university-science model had many well-known drivers: Bismarckian empire building, the rise of a sophisticated Prussian (and later, unified German) state bureaucracy, complex economic production, and some resistance to European democratic movements. However, what is often overlooked in this history is the profound change in the relationship between universities and society that enabled the entrepreneurial addition of scientific research to German and other Central European universities. Without this cultural shift, the rise of research-focused universities would not have progressed.

While the German university became the nursery for modern scientific research, the broader education revolution provided the enveloping cultural cradle for its revival. Prussia, and later Germany, was the first mover in this revolution, building upon compulsory schooling to expanding universities for a broader segment of graduates from the growing secondary education system, who sought new degrees

and professional opportunities (Windolf 1997). For example, while early in the 19th century, only 2–5 percent of young German men attended university, from 1870 to 1930, enrollment rates grew to 20 percent, with increasing numbers of women also attending. Despite the selective and highly stratified nature of secondary education, middle-class families began sending their sons to university—often the first in their extended families to do so—in hopes of securing technocratic positions in the civil service, the early welfare state, or large firms with growing organizational complexity. The initial university entrepreneurs launched an expansion that would have major repercussions for scientific research capacity. Late 19th Century Germany’s approximately 30 research-producing universities had expanded faster than those in France, entering the 20th century with more research capacity than the larger U.S., which would not surpass Germany in number of research universities until the 1920s (Powell, Baker & Fernandez 2017).

The University as the Corporate Unit and Collaborative Complex of Discovery

Once a new institutional arrangement is initiated, NIT hypothesizes that institutional autonomy requires a set of similar organizations—corporate units—legitimated to manage increased complexity of the institution and its tradeoffs. These units operate in formal, bounded spaces where the institution’s actors carry out core activities and acquire resources (Abrutyn 2013b). After initially serving as entrepreneurial agents, and borrowing innovations from newcomers like mid-century American universities, universities worldwide became the essential corporate units for science and essential for commercialization as well as the public good (Fernandez et al. 2021; Geiger & Sa 2008; Kameko 2024; Levine 2021; Owen-Smith 2018). As shown in Table 2, between 1900 and 1950, the number of research-intensive universities doubled and spread to more countries, supported by a global enrollment rate that also was doubling approximately every eight years. Cross-subsidized by a postsecondary education sector that, by 2010, enrolled just under a third of the world’s youth—and would grow to about 40% by 2020—a vast global university-based research conglomerate expanded by 2,696% from mid-century to 1980 (Baker & Powell 2024). By 2020, this conglomerate reached approximately 41,000 universities and other higher education organizations whose faculty-scientists produced scientific papers in 220 countries and jurisdictions.

Driven by well-known isomorphic pressures operating among fields of formal organizations, universities worldwide not only train future scientists in similar fashion, they also routinely monopolize, distribute, and conserve both physical and intangible symbolic resources necessary for research, largely supported by the immense cross-subsidies from their educational mission (Baker 2014; DiMaggio & Powell 1983; Geiger & Sa 2008). By expanding the internal complexity and external breadth of scientization, universities handle the costly tasks of credentialing, evaluating scientific potential, as well as the hiring, paying, and managing career development for most scientists globally (Baker & Powell 2024). They also provide the physical plant and administrative support for all activities related to day-to-day scientific research. Moreover, universities validate and maintain the horizontal and vertical organizational differentiation of research roles, distributing resources based on scien-

tific experience, expertise, and effectiveness, all structured by the common cognitive framework of science. They also manage inevitable competition and internal conflicts arising from the increasingly intertwined but contrasting missions of teaching and research; and, growing also is the third mission of contributions to economy and society via knowledge transfer (Owen-Smith 2018).

To demonstrate upper levels of the scale of this arrangement, consider a large, contemporary American research-intensive university (classified as R1 in the Carnegie classification). Here the university-science model is enacted across multiple colleges (as many as nine or ten faculties) of core discipline faculty-scientists. These scientists, ranging from tenure-track assistant to full professors, are a university regulated personnel classification routinely in the hundreds at any single college who conduct independent research culminating in published STEM papers. Their research is further aided by highly skilled staff, including PhD or near-PhD assistants (postdoctoral researchers, graduate students, and full-time technicians), whose numbers often double those of core faculty. Depending on the overall university enrollment, there is a cross subsidized by as many as 80 to 100 undergraduate majors and non-major students enrolled per each core faculty scientist. This may be further subsidized by approximately one teaching-only faculty member for every four core scientists (Baker & Powell 2024). While external research funding from nation-states, NGOs, and multilateral agencies is essential for specialized equipment and research support, even the most generous and consistent external funding, including indirect allocations for universities, does not cover the substantial costs of maintaining foundational research personnel and capacities at universities.

Disseminated globally, with predictable variations in scale, funding, and state control, universities have had a significant influence on scientific productivity. As the annual volume of STEM papers continued to grow exponentially, university-based faculty scientists were involved in two-thirds of these papers in 1980, increasing to 85% of over a million new papers by 2010 and 90% of the annual several million papers by 2020 (Table 2, second row). Additionally, the majority of these papers across the century were authored solely by university-based scientists. Individual universities have expanded their research capacity to such an extent that the annual number of STEM papers by contemporary science faculty across any two or three of the world's 100 most productive institutions is more than the global total in 1900. National studies also show that educational cross-subsidies of research are more closely associated with scientific production than either population size or government science funding in China, France, Germany, Japan, Qatar, South Korea, the U.K., the U.S., and in cross-national comparisons (Crist 2017; Fernandez et al. 2021; Fu 2017; Kim & Choi 2017; Powell & Dusdal 2017a, 2017b; Shima 2017; Zapp 2017; Zhang, Sun, & Bao 2017). And as science has expanded, reflected in the growth in journals where most STEM papers appear, this institutional arrangement has normalized and spread globally, fueled by increasing enrollments in higher education (Table 2, third, fourth, fifth rows). Predictably, increased scientization has also led to more non-university organizations—such as independent and state-sponsored research institutes, firms, and NGOs—that fund basic research, with their staff scientists contributing to the publication of papers, often collaborating with university-based colleagues. However, the non-academic sector's share remains modest

compared to the massive output from universities and research institutes (Dusdal et al. 2021).

Transcending the nation-states that host them and even geopolitical tensions, universities—through the enacted university-science model, common goals and practices, and advances in information technology (e.g., Internet)—have become the essential organizations facilitating most scientific exchanges. This has resulted in a massive *collaboration dividend* in scientific productivity, which is arguably the most significant addition to global science in the past fifty years, a major reason why science's carry capacity continues long after Price's prediction (Baker & Powell 2024). In 1900, while most papers in major STEMM journals had more than one author, these co-authors were usually colleagues from the same university laboratory or field station. Very few papers included scientists working in universities across different countries. Fifty years later, as shown in the sixth row of Table 2, collaboration patterns had not changed much, and even by 1980, the proportion of international collaborations had only doubled to 2%, albeit of a much larger total number of papers.

This changed significantly over the next decades. By 2010, nearly all research papers were collaborative, with international collaborations accounting for about a fifth of all papers—translating to over a quarter of a million papers authored annually by scientists working together across the globe (Baker & Powell 2024; for corroborating estimates, see Aksnes & Sivertsen 2023). The complexity of collaborations increased along with its ubiquity (Dusdal & Powell 2021). In 1980, the average collaborative paper found in main STEMM journals had two or three co-authors, with most collaborations involving no more than five authors. By 2010, this had grown to an average of six co-authors, with many papers involving 7 to 30 co-authors. Additionally, there were several hundred super-collaborative publications in 2010, each with between 100 and over 3,000 co-authors. By 2020, collaborative international papers continued to grow, as did super-collaborative papers. The collaboration dividend accelerated scientific growth over the past 40 years, plus there is recent evidence that it produces a high share of impactful research (Adams et al. 2019; Hackett et al. 2021). These trends, facilitated by the hubs of universities, attest to the multiplier effect of universities in providing physical resources, banking scientific talent, and offering access to unique instruments and data. University-fueled collaboration, even more than inexpensive, instant communication, not only enhances the efficient use of physical resources but also leverages scientific human capital across great distances, advancing the process of global scientization.

Two historical trends illustrate this. First, as the global center of scientific productivity shifted, three geographical hubs of intense, primarily university-based, collaborative research emerged first in North America, then in Europe, followed by East Asia. As the pace of international collaborative papers increased, these networks incorporated scientists from universities in more countries and regions into joint projects. For instance, the number of papers co-authored by scientists from the 20 countries that collaborate most with U.S.-based scientists grew from approximately 3,500 in 1980 to over 99,000 by 2011, an increase of 2,443% (Baker & Powell 2024). Similar trends in international collaboration can be observed in the European and East Asian hubs. Second, over the past few decades, collaborative hubs at research-intensive universities have increasingly drawn in scientists from traditionally non-

research postsecondary institutions and less-productive universities, as well as from autonomous research institutes (Dusdal et al. 2020; Fu et al. 2020). For example, through collaborations with research-intensive universities, papers authored by scientists from U.S. postsecondary institutions not traditionally involved in research grew by 171%, reaching approximately 190,000 papers in 2010. In many fields, university driven collaboration is now essential for discovery, becoming so widespread that it is likely to be the standard process for most, if not all, future research (Bozeman & Boardman 2014; Dusdal & Powell 2021; Kwiek 2021).

Universities and the Hegemony of the Scientific Journal Paper

In 1859, Darwin published his evolution theory and evidence in the book *Origins of Species*, forty years later Einstein announced relativity theory in a paper appearing in the journal *Annalen der Physik*. A subtle shift in medium that nevertheless marked the beginning of the third institutionalizing process in which universities are central—the scientific journal paper as science’s generalized symbolic medium of value and exchange (GSM)—a key element for the maturation of an autonomous institution (Abrutyn 2009; Luhmann 1995; Murakami 1997; Parsons 1951). While scientists communicate in various forms, the globally recognized gold standard for declaring discoveries is to write a paper in a highly prescribed format, subject it to anonymous peer review, have it vetted, accepted, and published in a scientific journal (and, more recently, the peer reviewed conference abstract). More than just the preferred format for archivable, formal communication of scientific findings, the peer-reviewed journal article is highly generalized in that papers and their review processes have become increasingly standard in form, procedure, and meaning. They are a symbolic medium in the sense that published papers take on value beyond their manifest content providing symbolic closure of an autonomizing institution. Individuals are ‘real’ scientists to the degree that they produce papers just as ‘real’ science occurs chiefly in lineages of papers recorded in citation histories. They are exchangeable in that papers hold value, allowing scientists to obtain physical and intangible resources such as positions, salaries, research funding, prestige, awards, and scientific reputation (Kaltenbrunner et al. 2022).

GSMs are often contested, not singular, or fully normative within institutions, but as they approach these qualities, institutional autonomy strengthens (Bourdieu 1977). Earlier institutional analyses identified ‘knowledge’ as the GSM of science. However, while knowledge is the ultimate foundation, it is too abstract, amorphous, and ubiquitous to serve as the basis for building a mature institution. Since Einstein’s era, papers and journals have increasingly assumed this institutional role, with universities acting as the key fiduciaries of the paper’s value as a GSM, central to the scientization process. Scientific journals, initially sponsored by proto-entrepreneurial royal academies, began using a peer review process as early as 1665 with the journal *Philosophical Transactions* (Fyfe et al. 2022). By 1900, faculty-scientists were regularly publishing STEMM papers in an expanding array of journals, many of which were written in German, the scientific *lingua franca* at the time. As shown in the fourth row of Table 2, the number of mainstream STEMM journals increased by over 700% from 1950 to 1980, and by an additional 110% by 2010, with a 2020 estimate

of over 9,500 of the most influential and cited STEMM journals (Web of Science Group 2022). Today, leading academic journals, as one of the key social structures of science, may need to defend themselves against alternatives, driven by information technology, yet despite changes to the ways scientific literature is produced and accessed, its definition reflects path dependence—peer-reviewed papers appearing in periodicals written for and read by specialists within differentiated scientific communities (Csiszar 2018: 281ff.).

As the GSM of science, papers determine the central prestige hierarchy of scientific achievement, and increasingly, the prestige of universities as well. The growth in papers, journal subject areas, and the number of scientists has transformed journals and their articles into a multi-billion-dollar, highly profitable global publishing industry. And the creation (and discontinuation) of journals reflects not only the absolute volume of scientific output but also the scientization process, which drives expansion and change in emerging research fields (Mabe 2003; Tenopir & King 2014; Ware & Mabe 2015).

As long noted by the sociology of science, establishing journals and the management of review processes and journal staff behavior were part of an autopoietic, self-professionalizing process undertaken by formal collectives of scientists (Merton 1973). By the 1960s, institutional entrepreneurial actions by scientists on the governing board of the high-profile journal *Nature* had established a standard set of review procedures and journal practices, shaping the norms for the entire institution of science (Wang & Barabási 2021). Thus, the paper as the GSM reinforces the institution's common cognitive framework for conducting research, strengthens communication networks, universalizes goals, organizes activities, and distributes resources to scientists. Even non-academic organizations—such as firms, international organizations, and NGOs—increasingly produce papers on a vast scale (Zapp 2017).

Parallel to this, universities—motivated in part by their self-interest in national and international prestige rankings—have increasingly become the organizational trustee and promoter of science's cognitive framework, enhancing the institution's autonomy (Shin & Toutkoushian 2011). This arrangement amplifies the value of the GSM in three ways: elaboration of value, control of value, and new uses of value to extend the inner workings of scientific research. First, since the early 20th century, universities have elaborated the value of scientific papers, moving from simple counts and informal journal reputations to complex indexes of quantity and quality, such as citation analyses (e.g., h-index, h5-index, g-index, i10-index, Impact Factors, Field-weighted Citation Impact). These measures, initiated since the mid-20th century, are now routinely used in academia as currency for recruitment, scientific evaluation, and resource allocation (Garfield 1955; Schimanski & Alperin 2018). Other, newer indicators, such as Altmetric and PlumX indices, track immediate diffusion and the societal impact of faculty-scientists' papers. Universities also use public relations efforts to highlight the number of papers as evidence of progress on societal issues—such as research on diseases—that then become a routine medium for media coverage, further heightening the symbolic value of the GSM (Brainard 2020).

Second, universities assert themselves as legitimate authorities—although do not always behave as such in actual cases—in controlling the GSM by adjudicating significant breaches in the cognitive framework of science. They can manage

investigations and sanctions for research misconduct, such as fraud, rule-breaking, mistreatment of subjects, and exaggeration in papers—ensuring increasingly higher standards of oversight. This role is evident in cases like the recent removal of a U.S. research university president by its Board of Trustees—not for outright fraud, but for failing to adequately address weaknesses in a small set of past journal papers from his laboratory when he was a faculty-scientist (Brooks 2023). Universities also monitor retraction notices, interest disclosures, and calls for greater public access to the technical details of papers. Although there are nevertheless more claims of adjudication by universities than actual behavior, no doubt because of conflicts with public image interests of which papers themselves are valuable assets, universities have increasingly declared and demonstrated their interests in papers, even as their support for book presses has been less constant. Finally, since the GSM is a taken-for-granted, universally accepted, and highly valued outcome of scientific research, it and its control by universities stimulate the global reach of the collaboration dividend.

Science-in-Crisis or Continued Scientization?

Inflated Science or Stable Exponential Growth?

With the massive increase in the volume of new papers, comes the temptation to conclude that science has become vacuously inflated by over-publishing, particularly due to the rise in the number of researchers since the latter half of the 20th century and especially after the 1980s. However, the perspective of scientization offers a different interpretation: not inflation, but a stable process of institutionalization where the core inputs to scientific activity—such as the number of scientists (currently estimated at close to 9 million) and its key output, published papers—have grown in tandem over time. This aligns with what we would expect from an increasingly autonomous institution, facilitated by universities as the corporate units expanding a common cognitive framework, and reinforced by the GSM of the paper. The autonomy also explains why our and others' bibliometric analyses do not find evidence of Price's distinct small science to big science stages over the 20th century, although this notion persists in contemporary analyses of research; in fact, the same dimensions of global mega-science have consistently intensified since the end of the 19th century if not before (Baker & Powell 2024; Price 1986 [1963], pp. 13–15). For example, since the mid-1600s, bibliometric analysis finds major growth phases in modern science, each tripling the previous growth rate: under 1% annually until the mid-18th century, 2–3% until the interwar period, and 8–9% up to 2010 (Bornmann & Mutz 2015). Another analysis, based upon 89 million digitized scientific papers published between 1900 and 2015, show that the global volume of papers has consistently doubled every 12 years, closely matched by the exponential growth in the number of scientists doubling every 11 years, which followed a similar trajectory up to the 1980s, with some acceleration thereafter (Dong et al. 2017; Zapp 2022). Notably, scientific productivity of individual scientists remains stable, with approximately two published papers per publishing scientist annually, until recently (Sinatra et al. 2016; Wang & Barabási 2021). Providing no evidence of widespread inflation in papers per scientist, this sug-

gests that the intellectual and skill challenges required to produce publishable results have remained relatively constant even as scientization has increased.

The slight rise in paper productivity to around 2.5 papers per scientist since the 1980s is likely due to the collaboration dividend necessary for complex scientific discovery—itsself another outcome of scientization (Wang & Barabási 2021). Even though the growth rate of new scientists at universities has slowed compared to the early 20th century, the collaboration dividend has sustained the exponential growth in published papers since the 1990s (Zapp 2022). While there has been some regional variation at different times, there is no evidence of hyperinflation in mainstream scientific publications. Rather, scientists and their core activities have grown at similar rates globally over the century, supported by cross-subsidized resources from the expanding post-secondary education system in region after region.

A Less Disruptive Science or Dynamics between Capacity and Content?

As noted above, even as scientific productivity continues to grow, large bibliometric analyses have been interpreted as supposedly demonstrating a decline in new ideas and disruptive research. For example, by operationalizing unique phrases in titles as indicators of new ideas, text analyses of 440,000 physics papers, 160,000 astronomy papers, and 19.6 million biomedicine journal papers published over various periods show that while publications in these fields increase exponentially, the appearance of new ideas (title phrases) declines (Milojević 2015). Additionally, by operationalizing instances of a small number of frequently cited, related papers as markers of canonization—which may hinder the flow of new ideas—another large study of 241 scientific fields, examining 1.8 billion citations from 90 million papers, found that larger main fields tend to have more canons than smaller subfields (Chu & Evans 2021). Furthermore, a study that operationalized citations to recent papers replacing frequently cited older papers as evidence of disruptive research found that the level of disruption has remained generally stable across 25 million papers published from 1945 to 2010, as well as among 3.9 million U.S. patents from 1976 to 2010 (Park et al. 2023).

These studies lead some to imagine a vacuousness about contemporary science. Even with limited operationalizations of otherwise complex processes and a failure to replicate sufficiently, extreme conclusions drawn, often by pundits, are considerably beyond the bibliometric facts (Holst et al. 2024). Some even go so far as to invoke crisis idioms—such as “ideational stagnation,” “plateauing of disruptive science and technology,” “cognitive flattening,” and “narrowing of knowledge”—all implying a sense of intellectual stagnation and fueling crisis narratives about the future of science (Fanelli 2018). By contrast, there is a five-point case about these patterns that, rather than indicating intellectual decline, reflects a predictable shift in the dynamics between research capacity and content due to increasing scientization.

First, in the narrowest sense, extreme disruption could decline, but not necessarily science with it. With growing scientization, ideational disruption comes in more diverse forms and becomes more interconnected with past developments. The size, pace, and institutional interconnectedness of contemporary science mean that the interaction between scientific capacity and content increasingly transcends histori-

cal limitations on scientific knowledge, leading to the vast accumulation of timeless ideas, all of which remain researchable for new discoveries. Universities, through their mandate to introduce new streams of scientific training linked to previous generations, fully enable this process.

Second, the popular “low-hanging fruit” analogy, which assumes that most of the big ideas have already been researched, overlooks the critical feature of modern science’s extensive capacity to explore ideas—whether they are long-established, renewed by recent findings or instrumentation, or entirely new (Jones 2009). Moreover, new ideas are not isolated; they evolve or fade through dynamic interactions with other ideas, often from different subfields. A notable example is the so-called “AI winter,” where the theoretical groundwork for artificial intelligence, laid in the mid-20th century (a disruptive idea at the time), had to wait until later computational advancements—based on other disruptive ideas and technologies—to flourish and expand into more STEM research. Bibliometric analyses have termed such phenomena “sleeping beauties,” (van Raan 2004) and there may be many more waiting to emerge, potentially creating significant disruption, as when methodological toolkits advance as one of the major pathways to further discoveries (Krauss 2024).

Third, sleeping beauties are just one example of the dynamic relationship between research capacity and content. Beyond the classic notion of the major disruptive new idea—which has likely always been relatively rare—large-scale contemporary science can increasingly explore a wide range of ideas, such as underdeveloped past theories, former dead-ends, unresolved paradoxes, hints in older findings, and minor refinements of existing ideas. For instance, recent bibliometric analysis shows that when novel ideas are integrated into existing networks of ideas, they are more likely to be researched than those that remain on the periphery (Cheng et al. 2023).

Fourth, with greater capacity, science can advance larger networks of ideas and more quickly incorporate related findings from other domains. Although most papers experience their highest citation rates shortly after publication, following a predictable “jump-decay” pattern, the mean length of time relevant papers are cited has increased by 33%—from 7.5 years to 10 years—since 1970, likely due to growing scientization, a trend beginning well before digitalization, search engines, and AI technologies were available (Sinatra et al. 2015; Wang & Barabási 2021; Wang et al. 2013).

Last, rather than only signaling ideational stagnation, the authors of one of these studies note that some degree of canonization serves as a heuristic in scientists’ cognitive maps, helping them navigate science’s expanding capacity to investigate various types of ideas (Chu & Evans 2021). Given the increasing inputs and dimensions of mega-science, expecting a constant rate of exponential growth in entirely new ideas is unrealistic (Bloom et al. 2020). However, the richness of the contemporary ideational environment and the vast research capacity suggest that science is far from stagnation. If anything, the opposite can be argued.

Too Many Scientists or Intensifying Competitive Swarm?

Estimates of the research and development workforce, including all scientists, indicate a tripling in higher-income countries and a doubling in middle-income countries

since 1980 (Zapp 2022). This growth in research activity leads to the emergence of new subfields, and enterprising faculty at universities often establish new graduate programs with associated curricula and degrees. While some of these programs do not endure, others do and may spread rapidly across universities worldwide. As the largest trainer of scientists for most of the 20th century, the U.S. attracted extraordinary numbers of talented young scientists, with its annual output of new STEM PhDs rising sixfold between 1920 and 2010 (Fernandez et al. 2021).

A growing scientific workforce can create the impression of a global ‘overproduction’ of scientists. A tempting conclusion particularly when paired with bibliometric evidence showing that productivity, measured by the number of papers published by scientists, follows a ‘fat-tailed distribution’ (e.g., lognormal fit), reinforcing a notion that there can only be so many talented scientists. Also, since at least the late 1960s, many scientists have authored modest numbers of papers, while a relatively small proportion have produced exceptionally large volumes. And this stratification of scientific output remains relatively constant throughout scientists’ careers (Fronczak et al. 2007; Kwiek & Roszka 2022). A similar pattern exists in the quality of papers, measured by citations: many papers receive modest citation counts, while a smaller proportion garner exceptionally large numbers (Kaur et al. 2013).

Countering the conclusion of too many researchers and overproduction from these trends, however, is the fact that successful institutions naturally attract more participants to their core activities over time. The exponential growth in scientists is not unexpected, and from the scientization perspective the global science system largely benefits from having more scientists (Powell & Baker 2021). Although there have been periods when the institution struggled to fully absorb new cohorts of university-trained researchers, and concerns about overproduction persist, the long-term growth in scientific training has been a major driver of scientization (K. Powell 2015). Similarly, if the old view of a genius-driven enterprise without much need for larger stocks of researchers was ever accurate, it is no longer (Bloom et al. 2020; Wang & Barabasi 2021). With increased institutional autonomy comes greater horizontal and vertical differentiation in roles and skill sets within scientific teams, enabling more complex collaborations. For instance, it has long been known that exceptionally talented scientists often thrive in teamwork, requiring a steady supply of scientists to form effective teams. At the same time, teams with a higher ratio of junior and specialist researchers to senior scientists are generally more productive than top-heavy teams (Wuchty et al. 2007). This is even more salient given the “random impact rule” suggesting that a scientist’s most influential research can occur at any point in their career. And while there is a modest negative correlation between age and innovative research, the average age of a scientist’s greatest impact has steadily increased over the past century (Jones 2009; Sinatra et al. 2016). Moreover, as scientization progresses, larger stocks of scientists expand research into other areas of society. This is evidenced by the historical growth of R&D activities in firms and the increasing reliance of patents on the content of journal papers, leading to more effective products and knowledge spillovers into other sectors (Jaffe et al. 2000; Trajtenberg 1990; Zapp 2017). While a growing stock of scientists can create inefficiencies in the labor market and pose challenges, it does not necessarily result in a weaker scientific enterprise.

Futures of Scientization

The brief historical descriptions here are part of a broad bibliometric panorama revealing a robust, autonomizing global institution of science; pieces of which Price began to describe sixty years ago in his groundbreaking book. Added is the central, but often underappreciated, dimension of an institution cross-subsidized by the education revolution, whose expanding universities transformed their relationship with society and knowledge generation (Baker & Powell 2024). The world continues to move toward greater scientization, gradual regional parity, and inclusion of universities and their researchers from all countries in global mega-science, largely due to the continued boundary-spanning influence of the university-science model. Furthermore, consistent with the argument about scientization, it is just one part of the university's broad impact on disciplines, including social sciences, humanities, and professional fields (Schofer et al. 2021; Stock et al. 2023b, a).

Universities do not merely provide a backdrop for science. In line with sociological theory on the creation and establishment of social institutions, universities have played active and necessary institutionalizing roles. First, they served as institutional entrepreneurs; then, they became the main corporate units facilitating the scientific labor force and global discovery networks; finally, they now act as a key fiduciary of the scientific paper, the institution's effective GSM. This socio-historical account opens new avenues of inquiry for both the sociology of science and the history of science. It may also help temper contemporary concerns about a perceived quality crisis in science. Like Price's flawed prediction—which unfortunately overshadowed the significance of his bibliometric approach—the massive growth of global mega-science can be difficult to grasp, potentially leading to cynical interpretations. As outlined here though, the scientization perspective offers alternative conclusions to those found in popular narratives of a crisis in scientific quality. These are essentially hypotheses awaiting testing in future analyses. If the scientization perspective helps correct early and contemporary misunderstandings, what might it suggest for the future of the institution? This raises important questions about the future of both institutions of education and science.

Will the deepening of the collaboration dividend compensate for emerging threats to the cross-subsidizing university-science model? Despite the unfortunate timing of his prediction, Price was correct in suggesting that exponential growth trends eventually slow to more moderate rates. However, how quickly that happens depends on the sustainability of the carrying capacity behind these trends. Known threats to the continued development of advanced education include shortages of people, funding, and effective governance (Baker 2024). While a full discussion of these challenges is beyond the scope here, two—a declining population in key science-producing countries and political interference—illustrate future barriers to scientization.

The historical record of (higher) educational expansion suggests a robust process, but its future requires venturing into new territory—literally. The regions with the largest cohorts of youth still to be included in advanced education are countries that have made significant, though imperfect, progress in developing primary and lower-secondary education for most of their populations. It remains to be seen whether many countries in Africa, parts of Southeast Asia, and South America can transform

past educational progress into postsecondary development, and to what extent. Many countries worldwide, including in these regions, have continued to develop upper-secondary and postsecondary education, but due to the legacy of massive exploitation of natural resources and people, as well as ongoing global inequalities, these areas are particularly vulnerable to challenges in further educational development. Nonetheless, there is recent evidence of growth in postsecondary education in the Global South (Higher Education Associates 2022).

Also, while a substantial portion of the world's youth still awaits enrollment in postsecondary education, plummeting birth rates in many countries are leading to limited growth or even decline in the higher education sector, particularly in some of the most scientifically productive regions. South Korea, for example, which rapidly expanded its education system and hence became a major contributor to global research, is now consolidating and closing universities due to its falling sub-replacement birth rate. Nevertheless, South Korea also demonstrates three key factors that may sustain the future of higher education and research. First, this country expanded postsecondary enrollment to include almost its entire youth cohort, suggesting that there may not be a premature limit to advanced education—indicating significant global capacity for further growth in higher education among the approximately 60% of the global youth cohort not yet attending postsecondary education. Second, like other late adopters of the university-science model, Korea successfully implemented graduate training and built faculty research capacity across a broad range of universities, although ongoing budget struggles may impact future research funding (Fu et al. 2020). Last, the country's scientists have benefited greatly from the international collaboration dividend, facilitated primarily by its universities, in a rapid and wide-reaching manner (Yu 2023). Rather than predicting a collapse of the university-science model, a more realistic outlook is that universities, through their collaboration dividend, will continue to transform scientific research via teamwork to meet future challenges.

A second example of barriers to sustainability centers on whether future scientization will continue to serve as an institutional cross-subsidy for universities. While universities already enjoy considerable prestige due to their central role in knowledge production—particularly through science, which remains a highly visible and legitimizing enterprise—this prestige does not always translate into direct financial gain, a common misperception given different commercialization policies (Kameo 2024). Scientific research is often too costly to serve as a primary revenue stream, but it does bolster institutional legitimacy and reputation. The early ethos of research collaboration, once epitomized by the “invisible college” of scientists, has since expanded and intensified, permeating the entire postsecondary education sector (Crane 1972). Increasingly, a wide array of postsecondary organizations engages in research activities further reinforcing universities' role in global knowledge production. At the same time, recent political attacks on universities and scientific autonomy—in countries such as Hungary and the United States—raise grave concerns about harm to the capacity and legitimacy of universities and their research missions. Evidence suggests that restriction on academic freedom is associated with declines in scientific publishing (Fernandez et al. 2024; Fernandez & Hutchens 2025). Yet, given the broader and resilient forces driving global scientization, it remains debat-

able to what extent such suppression will ultimately slow the global pace of science (Weingart 2025).

Regardless of the future of the university-science model, could there be a natural limit to scientific investigation, or at least to high-quality discovery? This is a complex epistemological question without a simple answer, but the appeal of predicting an imminent limit to science seems perennial. NIT and the scientization perspective instead suggest that on an institutional level science possesses much of what it needs to continue autonomizing into the future through its powerful broadening and deepening forces. The issue may not be a looming quality crisis in science but rather changes in the patterns and rhythms of discovery brought about by extraordinary scientization. Perhaps the popular specter of collapse, both in the past and now, ironically reflects this. Robust social institutions always create social challenges from their success in defining and redefining reality, ultimately a process ripe for some backlash. Why should expanding mass education and massive globe-spanning scientization be any different?

Declarations

Conflicts of interest All authors declare that they have no conflicts of interest.

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