

Europe Twice Enabled Contemporary Global Science, Too Few Appreciate It.

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Since the turn of the 20th century, the number of scientific journal research articles reporting new discoveries—from the mundane to the sublime—has unceasingly doubled nearly every decade. Today, the annual volume is well over three million papers, the majority of which appear in thousands of globally accessible, main scientific journals covering the range of the sciences, especially science, technology, engineering, mathematics, and medicine (STEMM), and appearing in many languages but chiefly the contemporary lingua franca of English. Too often dialogue about the state of science is needlessly nationalistic, with an overabundance of references to scientific and technology competition between the U.S. and China (e.g. *The Economist* 2024). What most observers do not appreciate is that Europe has twice played a pivotal role—at critical junctures—in the development of what can fittingly be described as *global mega-science*, without which the world's STEMM knowledge would be significantly less advanced than it is now.

Already at the end of the 19th century, regions of Europe developed an innovative organizational model that would lead to a societal cross-subsidy of research as never before. Then, in the early 1980s, not long after expert science-observers predicted an imminent collapse in the rate of new discoveries—and well before Asia's major contributions came online—papers published by European scientists surpassed those contributed by North American scientists. The region of small and mid-sized countries gave the world a super-hub of scientific collaboration, significantly increasing globalization of research and in the process saving the pace of science from stagnation. In both instances, it was the European research university, frequently maligned in science policy, that proved to be the decisive organizational form at the heart of scientific innovation and knowledge production for the world, facilitating mega-science on a global scale (Baker & Powell 2024).

Europe's Model for a New Kind of University

Global mega-science is societally cross-subsidized, complexly collaborative, and nationally transcendent. Universities are essential to these core properties, not only because they train future scientists, but also because they serve as the primary organizational platform for research—a model originating in Europe and spreading worldwide since. However, when pundits discuss the global production of scientific discovery, they often frame their narratives around three misleading images, each obscuring Europe's crucial role in establishing these qualities. First, they depict science as primarily driven by money, warfare, and the demands of capitalistic technological development. Second, they envision science as a national product, heavily influenced by individual countries' science policies and resources. Lastly, they take for granted the central role of universities in global mega-science, often treating their contribution as trivial.

Bibliometric assessments of the who, what, where, and when of millions of papers over the past century and a quarter cast a very different image of the forces behind the fundamental qualities of mega-science. Of course, many factors facilitate scientific knowledge production, including national policies, resources, and geopolitical

machinations, but from the Belle Époque onwards, an unexpected synergy between the ascending social institution of mass education and its expanding universities led to educational development cross-subsidizing scientific research—an arrangement launched in select European countries, in which research universities continue to contribute centrally to their local, national, and regional fortunes and futures. Although it is an erudite soundbite that 19th-century German-speaking universities were the “nurseries of modern research,” what is less appreciated is that this region hatched the world’s education revolution that fundamentally altered the relationship between education and society, and with that, the relationship among the university, scientific research, and society (Baker 2014; Vanderstraeten 2015, 2024).

Universities became less elitist and less classical as they broadened the scope of their teaching and scholarship. Prussia, then later Germany, and other European countries, such as France, Britain, and Denmark were the early movers of the “education revolution”, becoming “schooled societies” (Baker 2014) as systems expanded via compulsory primary schooling to broadening secondary education and finally, universities, serving ever-wider segments of students seeking new curricular offerings, certified knowledge and skills, and the degrees to leverage future occupational opportunities (Burns et al 2004; Hage et al. 1988; Stock, Mitterle & Baker 2024). Early in the 19th century, for example, only two to five percent of young German men attended university, then from 1870 to 1930 university enrollment rates grew to twenty percent of male youth, joined by a growing stream of young females. Even from a selective, highly stratified secondary education system, there was increasing inclusion from the middle ranks of German society into the university—sons of the bourgeoisie, large farm owners, technicians, artisans, and merchants were often the first among their extended families to attend university and were partially doing so in hopes of attaining new technocratic positions in the civil service, including an early welfare state apparatus, and in large-scale firms with intensifying organizational complexity (Windolf 1997). Growing rapidly with this new model, Germany’s approximately 30 research-producing universities would enter the first century of mega-science with new sources of enrollment and expanded research capacity, while it would not be until the 1920s that the much larger United States would surpass that number of research universities (Fernandez et al. 2020).



Europe, of course, developed the ancient university along a basic functional organizational form that is among the most continuous in Western society (Riddle 1993). But Europe's 18th-century moribund university, teaching an inflexible outdated scholasticism to hopelessly small enrollments, was the last organizational arrangement imaginable for scientific research (e.g., Paulsen 1895). One consequence of a wider inclusion of students at the university was for the education mission to cross-subsidize scholarship and research—ultimately resulting in what can be called the “university-science model” (Baker & Powell 2024). Responding to the burgeoning force of the education revolution, universities in Berlin, Erlangen, Göttingen, Halle, Hanover, Heidelberg, Leipzig, and beyond in Europe contributed to the innovations of the university-science model—a vision for the university that fused modest teaching duties with ample time and resources for scholarly pursuits and research and resulting in rapid intergenerational transfer of cutting-edge knowledge. This was a major transition in the basic form of the university, accomplished over a relatively short period, that would with increasing speed spread worldwide.

Cross-subsidizing research through teaching was reinforced by additional organizational innovations, including the invention of the academic seminar that paired seasoned faculty-scientists with students to engage in collaborative reading, discussion, and critique of ongoing scientific inquiries and theories. Also, the precursors to the independent academic department (institutes in European universities) developed, and equipped with teaching laboratories in various scientific disciplines such as astronomy, chemistry, mathematics, mechanics, physics, and technology. The logic behind the model also led eventually to the adoption of a “publish or perish” ethos within universities. This reflected hard-won academic freedom from state intervention in both curriculum development and research as well as the dissemination of the renowned “Berlin system” of faculty development that foreshadowed the contemporary global recruitment of scientist-faculty “stars” based upon the quantity and quality of their prior scientific output.

These innovative European universities were not merely setting the stage for research, their actions buttressed an ideology that would bind the university, fed by the persistent education revolution, to scientific inquiry. The model promoted the eponymous Humboldtian ideals of academic freedom, unity of teaching and research, broadest inquiry, and the primacy of “pure” or basic universal knowledge. Despite the widely acknowledged centrality of the model’s organizational innovations and its guiding ideals, they were not a result of a consensual, unidirectional linear process, but rather came about through sequences of growth, resistance, competition, inertia, and even episodes of retrenchment. They never represented a formally articulated organizational blueprint for universities in Germany or elsewhere, nor did they wholly spring from Wilhelm von Humboldt, their ascribed originator. They were not part of one concisely derived master plan arising from a single university at a single point, as is often assumed about the University of Berlin (Ash 2006).

Nevertheless, in fits and starts, an exceedingly Eurocentric enterprise gave the world this new model for a university, which, with its organizational advantages, underpinned by a liberal ideology of discovery, spread globally. It proved extremely productive for science. By the end of the 19th century, there were approximately 130 research producing universities, mostly in Europe, with a growing number in North America and a few other places. Researching under the university-science model, faculty-scientists writing in the then main languages of science (English, French, German, and Russian) contributed to about ten thousand papers in scientific journals in just 1900. And over the ensuing fifty years, the number of research-intensive universities doubled, operating in almost forty countries supported by a world postsecondary education enrollment rate that was itself doubling approximately every eight years. Currently, there are over thirty-eight thousand universities spread over more than two hundred countries whose scientist-faculty are publishing STEMM papers (more when including all disciplines). Along with the evitable organizational and country variations, adaptations, and limitations, mostly the original European university-science model and its ideology operate at the heart of these institutions; a model supported by the education revolution’s inclusion of ever-more people into post-secondary education. Consequently, an estimated 85 percent of the millions of (mostly co-authored) annual papers are written by at least one university-

based scientist, and the majority of these are solely authored by university scientists (Baker & Powell 2024; Kosmutzky & Krücken 2024; Levine 2021). Learning from Europe, the original university-science model is now incorporated into all types of higher education institutions from the much touted late-20th century American super-research university along with rising ones in parts of Asia, South America, and elsewhere to lesser-known universities in all regions. This remarkable isomorphic process continues even though many science experts, including university leaders themselves, do not fully appreciate the university science model's historical European origins or what it meant for the building of global research capacity (Baker 2008).

Just before the university-science model truly went global, riding a mounting wave of postsecondary enrollments, an influential analysis in the 1960s argued that because scientific papers doubled every proceeding decade and since such logistic growth eventually stabilizes, there must soon be an inevitable scientific doomsday of insufficient new high-quality science—with the potential to harm the world's economy, equal to another Great Depression. The prediction from Derek de Solla Price's book *Little Science, Big Science and Beyond* ([1963] 1986) was for its time as notably bold as it would later prove strikingly incorrect. Price was wrong because, like other science observers, he underestimated the potential of the original European educational cross-subsidy of research at universities and highly collaborative science to spread well beyond North America to other world regions—including its return to a subsequent revival in Europe after the cataclysmic destruction of research capacity brought about by World War II.

Europe's Comeback and the "Collaboration Dividend"

Despite the havoc wreaked upon European universities and research production by the geo-political turmoil of the middle decades of the 20th century, by 1970 its scientists were contributing significant new volumes of discovery and were poised to again make major contributions to global mega-science, in countries such as Belgium, France, Germany, and Luxembourg (see Powell & Dusdal, 2016, 2017a,b). The faulty prediction of collapsing research productivity had also failed to anticipate the coming of a research "collaboration dividend," acting as a kind of multiplier effect that maximized the world's scientific human and physical capital and arguably enhanced research quality (Baker et al. forthcoming). As a world wave of postsecondary enrollments spread Europe's original university-model, commonalities in mission, motivation, and organization across universities enabled scientists to directly learn from colleagues, and form sustainable long-distance collaborations on common research pursuits. With the new century and at least partially transcending geopolitical issues, hundreds of thousands of papers resulted from international collaborations. For example, approximately a quarter of the one million papers appearing in 2011 came from international collaborations. Research complexity also grew as the average research team got larger and collective arrangements became more intricate, perhaps best reflected in the now annual several hundred super-collaborative papers from international teams ranging from 100 to over 3,000 contributing scientists (Aksnes & Sivertsen 2023).



Europe's revived universities, accustomed to competition and surpassing the limits of their smaller systems by working together, played a crucial role in this collaboration dividend, yet again without much notice. By 1980, well before the highly touted rise of science from East Asia, European scientists quietly took the lead in authoring more of the world's scientific papers than any other region, and it was in large part because of its universities. Tracking the global distribution of origins of millions of papers shows how the

world's scientific center of gravity—measured as the sum of weighted geographic centroid including oceans of regions' total papers from 1900 to 2010—moved during the century of science (Powell, Baker & Fernandez 2017; Zhang, Powell & Baker 2015). Over the first half of the 20th century, the center steadily traveled westward, away from Europe. The North American expansion of postsecondary education and adaptations to Europe's university-science model would by 1930 result in an explosion in scientific publications accounting for over half of the world's new discoveries. Just after WWII, however, the scientific center of gravity turned eastward, away from the North American shore, and slowly moved back towards Europe. By 1980, Europe's collective resurgence meant that scientists in the numerous countries of the eventual European Union—with its vast investments in collaborative research across the entire, and continuously expanding membership in the world's largest and increasingly knowledge-based economy—would overtake scientists working in the United States and Canada—and author the higher share of the world's ever-growing number of papers, continuing to do so at least until 2015.

Accounts of post-WWII period science are chiefly about American scientists' contributions. At least since the 1990s, the U.S.'s wealthy super-research universities, building upon numerous resource streams, public and private, have received more than their fair share of reputation (Geiger 2019). While the credit for their productivity is mostly deserved, this is also based upon academic mobility—the in-migration of young scientists filling doctoral programs (Fernandez et al. 2021)—as well as the collaboration dividend accruing to the value of North American research capacity and large-scale investments in infrastructure that support such boundary-spanning teamwork (Dusdal & Powell 2021). It is no surprise then that American and Canadian universities were the first super-hub of a growing network of international research collaborations. But anchored by the science powerhouses of France, Germany, Italy, and the U.K., Europe rapidly followed as the world's second super-hub of collaboration. By the 2000s, with supranational initiatives aimed at universities, European scientists internationally co-authored more articles than did their American counterparts, and like the latter, they are collaborating with scientists at an expanding number of countries in all world regions, including those with geopolitical limitations (Zapp, Marques, & Powell 2018). Consequently, the world's three top countries whose scientists author the most papers per capita are in Europe (Switzerland, Sweden, Netherlands), and six more are among the top twenty high-efficiency producers (UK, Germany, France, Spain, Italy, and Poland) (Baker & Powell 2024). Although Europe was not the first “super hub,” its scientists, mostly at universities, were dominant collaborators in the initial American one on its way to becoming the world's second super hub.

Europe's Quiet Research University

There are two main reasons why Europe's recent world-leading role in global mega-science is not better recognized. First, because of the tendency to only think of research output as a national product, not a world one, rarely is the regional influence of Europe considered as one. Images of a US-Soviet technology race during the Cold War and now a Sino-American science race often overshadow this gradual, quiet regional achievement

of incrementally advancing collaboration, not the loud superpower competition. For example, the recent trend of the proportion of annual papers attributable to Chinese scientists surpassing American ones became major news, yet the same accomplishment nearly four decades earlier by European scientists went virtually unnoticed. As the path of the world's center of scientific paper gravity illustrates, the 125 year-development of mega-science was first a story of European university-based science followed by a North American one, then one of a European revival followed by a broadening collaboration with North America, and only most recently a global one with major East Asian contributions (Baker & Powell 2024). This history anticipates growing contributions between Global North and South collaborators.



The second reason is that the role of the university over the past century and one-quarter in fostering global mega-science has not been robustly considered, overlooking a key factor in the telling of this history. And this is particularly the case for the European university. In images of the region's scientific success, its various national, autonomous research institutes, such as Max Planck Institutes or leading European research projects

(funded by the European Research Council or the European Commission) are celebrated, less its universities—a misrepresentation of universities' contributions reinforced by design. For example, Germany's dual-pillar policy assumes that the university educates and trains the next generation of researchers while the independent institutes produce research, implying the former have a lesser role in research reinforcing a diminished image of its universities (Dusdal et al. 2020). Empirically this has never been accurate and is certainly not the case today. Analyses of paper production over recent decades in Germany, the home of the most celebrated culture of autonomous institutes, and a select group of other Eastern European countries finds that not only are university-based scientists responsible for the largest share of annual production, their efficiency of production and quality are not significantly different from institute-based scientists; plus the former have led the way to international collaboration for more complex research (Chankseliani, Lovakov, & Pislyakov 2021; Dusdal et al. 2020).

This false contrast is beginning to change with a new vein of multilevel research on university alliances, bringing universities in different national contexts together to facilitate communication, coordination, and collaboration. For example, alongside dozens of alliances amongst European universities, the European Universities Initiative (EUI), launched as a pilot initiative in 2019 but now integrated into the EU's higher education policy framework program Erasmus+ strengthens connection, not only bilaterally, but regionally (Charret & Chankseliani, 2023; Cino Pagliarello, 2022; Marques & Graf 2023; Vukasovic & Stensaker 2018). European countries have increasingly invested in higher education and science systems, leading to rising numbers of scholars and scientists, considerable infrastructure development, and dense cross-cultural networks and collaboration (Powell & Dusdal 2018). Nevertheless, if the higher education and science studies communities had been more Europeanized from the start, they would have been more aware and vocal about the role of this central hub of knowledge production. Based upon its rebuilt post-WWII universities in countries of diverse size and structure, Europe's contributions to global mega-science, both at its beginning and later, have been notable and deserve to be more fully recognized today.

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Photographs of the University of Luxembourg's Belval Campus by Justin J.W. Powell (2016-2024)