Europe's Center of Science: Science Productivity in Belgium, France, Germany, and Luxembourg

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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. The result: significant growth in scientific output and productivity in science, technology, engineering and math (STEM) fields. For four EU member states in Western Europe of different size and institutionalization pathways of science, we assess the development and current state of universities and research institutes, and the resulting science output. We measure output in peer-reviewed research articles collected in Thomson Reuters' Science Citation Index Expanded (SCIE).

Based on a comprehensive historical database, this comparison uncovers both stable and dynamic patterns of productivity from 1975 to 2010 in Germany, France, Belgium, and Luxembourg.[1] This emphasizes different institutionalization pathways that created the conditions necessary for continuous, but varying growth in scientific productivity in the European center of global science. Today, these countries invest considerably in research and development (R&D) and in higher education, the smaller ones doing so through a single national research university (Luxembourg), or a set of strong research universities in different regions (Belgium's language communities of Flanders and Wallonia). The two larger countries (France and Germany) maintain differentiated systems of universities—of varying size and prestige—and extra-university research institutes that are connected in large umbrella associations or coordinated by government agencies. Rising science productivity reflects considerable state investment, yet the impact of any individual scientific article remains difficult to measure.

[1] The Science Productivity, Higher Education, Research Development, and the Knowledge Society (SPHERE) project created and analyzed a huge global dataset on scientific journal articles, published between 1900 and 2011. Combining a series of case studies from North America, Europe, the Middle East and East Asia, the project examines how systems of higher education developed and grew nations' capacity for scientific research. The analysis resulted in insights about global scientific production that were only possible through consideration of long-term trends. The research reported here was made possible by NPRP grant #5-1021-5-159 from the Qatar National Research Fund (a member of Qatar Foundation), yet the findings are solely the responsibility of the authors.

Internationalizing the Organization(s) of Scientific Productivity

On-going internationalization and Europeanization of higher education and science has been accompanied by increasing regional, national, and organizational competition, yet simultaneously collaboration among individual scientists has growth exponentially.[2] This emphasizes the powerful diffusion of worldwide ideas and norms in science.[3] Higher education has continued expanding globally,[4] with all countries investing in universities.[5] Yet despite worldwide expansion and convergence pressures, comparative institutional analyses also show persistent differences in higher education systems. Our sample of four countries reflects the history and development of the research university as well as of independent research institutes. Belgium, France, Germany, and Luxembourg are connected in European multilevel governance, and participate in myriad joint higher education and research programs, such as Bologna, Erasmus, and Horizon 2020. At the intersection of the Germanophone and Francophone worlds, these countries differ in languages and cultures, in demographics and geography, and in the resources and infrastructures devoted to education and science. How have their varying investments in R&D and institutionalizations of higher education and science systems shaped their scientific productivity?

Measuring Scientific Productivity across Western Europe

Measured in papers published in leading peer-reviewed journals of the SCIE, the volume of scientific output differs, sometimes unexpectedly, according to the institutionalized structures of higher education and research systems. The database consists of a stratified random sample of published papers in selected STEM disciplines from 1900 to 2010. Together, these four countries contribute considerably to global scientific production, as their scientists publish a vast number of scientific papers. While each invests considerably in education and science at all levels, in absolute terms and per capita, alongside strong growth we find important differences in productivity, especially over the post-WWII period.

Europe: A Center of Global Scientific Productivity

Higher education and research, transmitting and producing knowledge in the *lingua franca* of the day, are thoroughly worldwide activities. Along with changes in the global "center" of science—France around 1800, Germany from 1840, and the United States since WWI—the language of science shifted from French to German to English, leading to the current dominance of Anglo-

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[2] Zhang, L., J.J.W. Powell & D.P. Baker. 2015. Exponential Growth and the Shifting Global Center of Gravity of Science Production, 1900–2011. *Change: The Magazine of Higher Learning* 47(4): 46–49.

[3] Drori, G.S., J.W. Meyer, F.O. Ramirez, and E. Schofer. 2003. *Science in the Modern World Polity*. Stanford: Stanford University Press.

[4] Schofer, E., and J.W. Meyer. 2005. The Worldwide Expansion of Higher Education in the Twentieth Century. *American Sociological Review* 70(6): 898–920.

[5] Baker, D.P. 2014. *The Schooled Society: The Educational Transformation of Culture*. Stanford: Stanford University Press.

phone journals.[6] The case selection portrays the shifting significance of these three leading scientific languages. Currently, English everywhere provides a (necessary) common communica-communication platform, especially in the STEM disciplines.

Home to many of the oldest research universities and other organizational forms, such as academies and research institutes, Europe is at the heart of scientific productivity between North America and East Asia.[7] Belgium, France, and Luxembourg host the European Union capital cities and all four countries are members in the Bologna Process, creating a European Higher Education Area.[8]

Higher Education and Science Systems of Different Scale and Scope

Yet these four countries differ in the scale, scope, and structuring of their systems, and in the developmental pathways of their universities and research institutes. While Belgium, France, and Germany have centuries-old, world-renowned research universities, Luxembourg has among the youngest in Europe, founded in the "Bologna" era. Among the oldest and leading research universities worldwide, the Université Paris–Sorbonne was founded circa 1150, the University of Heidelberg in 1386, and the Catholic University in Leuven in 1425. They all produce large numbers of publications and are globally interconnected. Especially Germany and France additionally have well-established extra-university research institutes, often linked in extensive associations that contribute hugely to these countries' scientific output—and are world leaders, e.g., France's *Centre national de la recherche scientifique* (CNRS) or Germany's Max Planck Society for the Advancement of Science (MPG). Especially in Belgium, but also in Germany, research universities are the most significant organizations for producing science. In France, and particularly in Luxembourg, research institutes have produced more STEM+ science; however, universities are catching up in both countries.

On the input side, comparing the investments in research and development shows considerable variance across Europe, as measured by the level of gross domestic expenditures on R&D (GERD) as a proportion of GDP. In 2008, two years before the last publications gathered in our database were published, the OECD mean was 2.29 percent while the EU-15 mean was 1.91 percent. Germany had increased its R&D investments to 2.60 percent. France has been relatively stable above 2 percent since 2000 (2.06 in 2008). Belgium invested 1.92 percent; just below France, but far lower than Germany. Luxembourg had a mean of 1.64 percent, lower

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[6] Ben-David, J. {1977} 1992. *Centers of Learning. Britain, France, Germany, United States*. New Brunswick, NJ: Transaction.

[7] Zhang, L., J.J.W. Powell, & D.P. Baker. 2015. Exponential Growth and the Shifting Global Center of Gravity of Science Production, 1900–2011. *Change: The Magazine of Higher Learning* 47(4): 46–49.

[8] Powell, J.J.W., N. Bernhard, & L. Graf. 2012. The Emergent European Model in Skill Formation: Comparing Higher Education and Vocational Training in the Bologna and Copenhagen Processes. *Sociology of Education* 85(3): 240–258.

than its three neighboring countries. None have reached the EU target of 3 percent to be invested in "innovation". Thus, these countries' investments vary by a factor of two.

This selection of countries reflects higher education and science systems with differently institutionalized organizational structures. Comparing the four research university sectors, Germany and Belgium, with their strong international research universities, have more highly institutionalized systems than do France and Luxembourg. By contrast, in research institutes, France and Germany have large, differentiated non-university research sectors, much more extensive than those in Belgium and Luxembourg.

Germany has dual pillars of strength, with a symbiosis of research universities and extra-university research institutes. Germany is home of the undisputed model of the research university and significant extra-university research institutions. Yet universities have been underfunded for decades.[9] The German "Humboldtian" model of university-based science is among the oldest and influential conceptions of higher education worldwide, reaching mythic proportions (to the point of controversy),[10] despite the ongoing transformation of German higher education—not least due to reunification that led to unforeseen, dramatic dynamics in academia. While the foundational principle of the nexus of research and teaching enjoys sustained attention worldwide, the relationship remains complex and ambiguous both within organizations and between the organizational fields of higher education and research. The success story of research-based teaching relies on academic autonomy and self-government, institutional and organizational growth, and its generality.[11] Germany's dual pillars of mass universities and independent research institutes continue to boast prodigious scientific output. The universities maintain their central position, despite state support not keeping pace with rising enrollments.

In **France**, elite professional higher education and research reflect hierarchy and access issues, as tertiary education and research are stratified: the *grandes écoles*/university divide, the split between selective and non-selective segments, and distinctions between CNRS researchers and academy members at the top and regular university faculty members below. France's differentiated higher education system consists of a range of universities, some quite strong in research and others devoted to teaching. Universities are challenged by the elite higher professional schools, the *grandes écoles,* to attract top talent. And in research, the *Centre national de la recherche scientifique* (CNRS) is dominant (also in terms of the production of papers in SCIE journals), though many of its researchers establish or work in research laboratories physically located

[9] Lenhardt, G. 2005. *Hochschulen in Deutschland und in den USA*. Wiesbaden: VS; Baker, David P. 2014. *The Schooled Society: The Educational Transformation of Culture*. Stanford: Stanford University Press.
[10] Ash, M.G., ed. 1999. *Mythos Humboldt*. Vienna: Böhlau.
[11] Ben-David, J. {1977} 1992. *Centers of Learning. Britain, France, Germany, United States*. New Brunswick, NJ: Transaction.

within universities. Currently, universities are being associated in consortia to strengthen their research networks and regional structures bring diverse organizational forms together (e.g., in the Paris-Saclay cluster). Nevertheless, research and teaching are less integrated than in Germany. France finances and maintains prestigious extra-university research units and institutes, many under the CNRS umbrella.

Turning now to **Belgium** and Luxembourg, we find two countries that have undergone significant transformations in higher education and research through European and within-nation policy interventions. Belgium exhibits considerable endogenous dynamics given the internal cleavages that exist, from early religious differences to linguistic and resulting geographic boundaries in a diverse country. Despite hosting the key European capital city, Belgium faces political challenges in maintaining a functioning nation-state. Belgium's strong research universities reflect such cleavages, with the Belgian education landscape divided into language communities also responsible for higher education and research policies. The two largest communities (Dutch-speaking and French-speaking) are in charge of higher education, while the German-speaking community in Eupen is much smaller and without its own university. Belgium is also articulated in three regions—Flanders, Wallonia and Brussels-Capital—with the capital city the only region in which the Dutch-speaking and French-speaking communities overlap; both have universities in Brussels. Although with a few research institutes, Belgium's key organizational form in both higher education and research is the university.

Luxembourg, as does its northern neighbor, shows considerable diversity in languages spoken. Over centuries, the Grand Duchy has been majorly influenced and affected by the countries with which it shares roots and borders; it long relied on them to provide most higher education and research.[12] Socially and demographically, Luxembourg is hyper-diverse and growing rapidly, reflected in science as well.[13] Luxembourg has built capacity through its public research centers and its national research university, founded in 2003, and built upon several precursor organizations.[14] Thus, while capacity remains limited, the past quarter-century has seen tremendous growth.[15] Luxembourg's small, but diverse higher education system is matched by a number of research institutes and medical facilities active in various scientific fields, with the University of Luxembourg now the centerpiece of the higher education and science systems.

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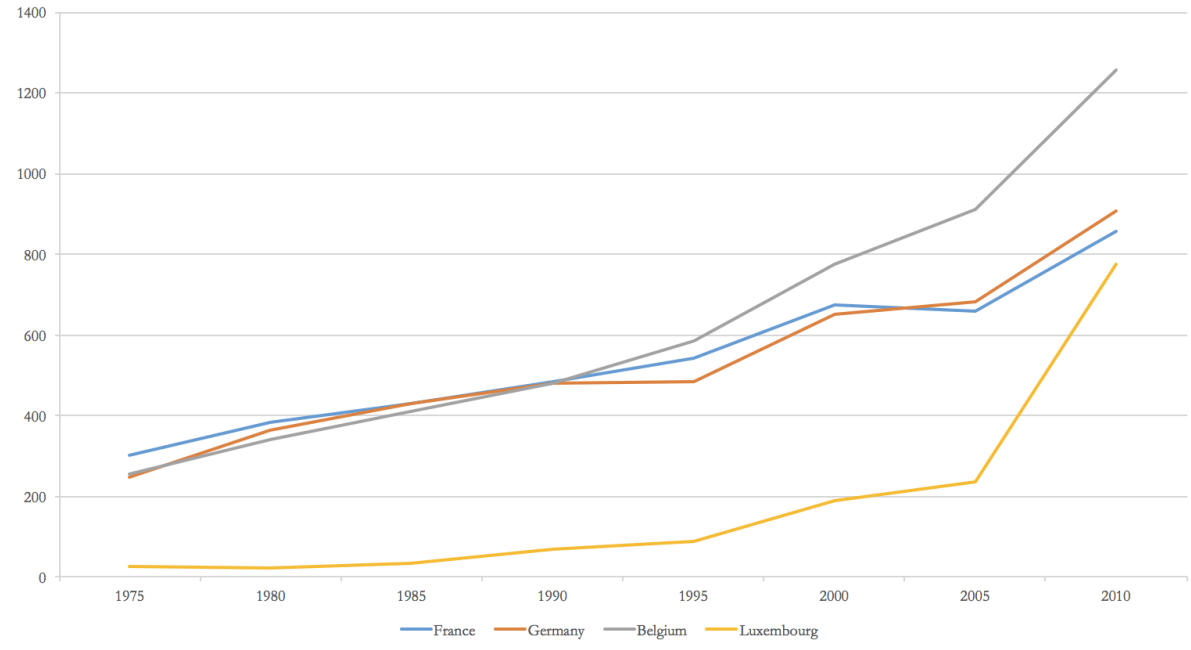
[12] Rohstock, A. & C. Schreiber. 2012. The Grand Duchy on the Grand Tour: A Historical Study of Student Migration in Luxembourg. *Paedagogica Historica* 49(2): 174-193.
[13] Meyer, M.B. 2008. The Dynamics of Science in a Small Country: The Case of Luxembourg. *Science and Public Policy* 35(5): 361–371.
[14] Braband, G. & J.J.W. Powell. 2016. Luxembourg's Expanding Higher Education System: Responding to Global Norms. *International Higher Education* 86: 27–28.
[15] Powell, J.J.W. 2012. Small State, Large World, Global University: Comparing Ascendant National Universities in Luxemburg and Qatar. *Current Issues in Comparative Education* 15(1): 100–113.

Comparing Countries' Scientific Productivity

The over time and cross-national comparisons emphasize that Germany, France, Belgium, and Luxembourg, as larger and smaller neighboring countries embedded in the European Union, have contrasting policies in R&D and varying investments and proportion of scientists of all employees. Their higher education and research systems reflect different institutionalization pathways and combinations of universities and institutes, each organizational form contributing more or less to scientific productivity. In each country, research universities and research institutes (often gathered in umbrella associations) contribute different proportions to overall scientific output, but in all four countries, and increasingly over time, the research university represents the key organizational form.

To enable a reliable measure of productivity based on SCIE publications in leading journals, and to interpret across cases of different size and science capacity, we calculate the scientific output per one million inhabitants (see Figure 1). While the long-term scientific strength of Germany (even during the division of West and East Germany) continues to the present day, it is Belgium, with its group of powerful, internationalized research universities, that leads in per capita productivity, followed by Germany, France, and Luxembourg (all relatively similar, with Luxembourg catching up through its late but intensive university expansion).

Figure 1: Number of STEM Publications from Belgium, Germany, France, and Luxembourg (per million inhabitants), 1975-2010



Source: SPHERE project database of SCIE publications (based on Thomson Reuters' Web of Science), OECD.Stat 2016.

Comparing the absolute productivity levels of countries historically manifests the dramatic expansion of higher education and the rise of science. The four countries examined here have, since the 1980s, witnessed a veritable boom in the publication of scientific articles in STEM+ disciplines. Comparing cases of very different size, of course issues of scale and scope must be acknowledged. If Germany spent by far the most on R&D, followed by France, Belgium, and Luxembourg, none reaches the EU 2020 benchmark of 3 percent.[16] Yet resources alone can fully explain neither the expansion nor the country-level differences found. Indeed, Luxembourg, spending less than half as much as its neighbors, has built capacity effectively in strategic fields. With targeted investments, Germany successfully recovered from the shock of reunification, but has not regained the top position of these four countries in Western Europe it enjoyed until the peaceful revolution of 1989/90.

Our study investigated the contributions of different research organizational forms to scientific productivity. We compared the production of STEM research in four larger and smaller countries in Europe. These countries achieve their scientific outputs having distinct and differently institutionalized higher education and science systems. Germany has long-established research universities and independent research institutes that produce a large number of articles—more than do the equivalent organizations in aggregate in France, Belgium, and Luxembourg. France, while relying on a group of strong universities, emphasizes teaching and has fewer such organizations than does Germany. France also funds a diversity of well-established research institutes and other organizational forms, including the influential and highly-productive CNRS. Still, France follows Germany in the total number of publications. Belgium has few research institutes; its capacity mainly relies on a small group of important, highly internationalized universities. Belgium is the leading country of these four, if we measure publication productivity relative to population.

Our key finding is that the institutionalization of the research university sector and reliance on it seems to support high productivity. In fact, those large and dual structured systems with a highly institutionalized non-university sector, as in France and Germany, have less per capita output than Belgium, with its highly-developed, well-funded university sector. Luxembourg, with its recently-founded research university and several research institutes, while catching up quickly, cannot yet match the other countries in relative terms. This also strengthens the small state thesis—of adaptability and comparative advantage—found in other parts of Europe.[17] Smaller European countries, in which basic research is mainly done in universities, are relatively more productive than the mid-sized, or even the largest science producers, which have strong non-

[16] OECD.stat. 2016. *Main Science and Technology Indicators.* http://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB, last accessed 4 November 2016.
[17] Meyer, M.B. 2008. The Dynamics of Science in a Small Country: The Case of Luxembourg. *Science and Public Policy* 35(5): 361-371.

university sectors receiving considerable resource shares.[18] Cole and Phelan (1999) have argued that wealth strongly, but not completely, influences the volume of research produced by countries.[19] Indeed, the proportion of researchers of the total labor force in these countries varies marginally, from 9.7 per 1000 employees in Belgium to 9.2 in France, 8.6 in Luxembourg and 8.4 in Germany.[20] Differences between these four wealthy European countries in scientific productivity cannot be fully explained by differences of overall investments in science or the number of researchers. Rather, the institutionalization and distribution of organizational forms—the infrastructures—in which researchers are producing science and the international collaborations upon which they rely remain crucial factors to be examined further.

In the European center of science, we found remarkable sustained growth, building on the evolving institutionalization of research universities and institutes and embeddedness in worldwide scientific networks. The elaboration of scientific communication through a world of scientific journals built upon peer-review and rising (inter)national competition and collaboration in the STEM fields spur global growth—with Europe still central in global science.

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[18] May, R.M. 1997. The Scientific Wealth of Nations. *Science* 275: 793-796.
[19] Cole, S. & T.J. Phelan. 1999. The Scientific Productivity of Nations. *Minerva* 37: 1-23.
[20] OECD.stat. 2016. *Main Science and Technology Indicators.* http://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB, last accessed 4 November 2016.