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Revisiting the Global Knowledge Economy: The Worldwide Expansion of Research and Development Personnel, 1980–2015

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Abstract Global science expansion and the 'skills premium' in labor markets have been extensively discussed in the literature on the global knowledge economy, yet the focus on, broadly-speaking, knowledge-related personnel as a key factor is surprisingly absent. This article draws on UIS and OECD data on research and development (R&D) personnel for the period 1980 to 2015 for up to N = 82 countries to gauge cross-national trends and to test a wide range of educational, economic, political and institutional determinants of general expansion as well as expansion by specific sectors (i.e. higher education vs corporate R&D) and country groups (OECD vs non-OECD). Findings show that, worldwide, the number of personnel involved in the creation of novel and original knowledge has risen dramatically in the past three decades, across sectors, with only a few countries reporting decrease. Educational (public governance, tertiary enrolment and professionalization) and economic predictors (R&D expenditures and gross national income) show strong effects. Expansion is also strongest in those countries embedded in global institutional networks, yet regardless of a democratic polity. I discuss the emergence of 'knowledge work' as a mass-scale and worldwide phenomenon and map out consequences for the analysis of such a profound transformation, which involves both an educated workforce and the strong role of the state.

Keywords Research and development expansion · Knowledge economy · Knowledge-intensive personnel · Knowledge work

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Introduction

Starting in the late 1960s, although much more evident since the late 1990s, the terms "knowledge economy" or "knowledge society" have been used to describe a fundamental shift in how modern societies view economic resources, value production and the bases of political, social and cultural life. Such a "post-industrial economy" would be characterized by a stronger premium on skills, innovation, research, development and university knowledge (Drucker 1969; Bell 1973; Frank and Meyer 2020; Stehr 1994; Välimaa and Hoffman 2008).

Indeed, at least formally, the knowledge base of societies around the world has increased considerably in the post-World War II era indicated by rising numbers of universities, students, science associations and publications as well as rising levels of funding and efforts to scientize policymaking. These changes are accompanied by a political discourse that stresses scientific knowledge, innovation, and excellence as drivers of social and economic development making the notion of the "knowledge economy" both a sociological diagnosis and a political agenda (Drori et al. 2003; Moisio 2018).

It seems that modern societies are rapidly moving towards the "schooled society" – a concept that describes societies' transformation toward social systems that are characterized by the expansion of education and science and whose signature is a profoundly reshaped economic system and labor market where non-material goods and creative skills are becoming critical resources (Baker 2014; Goldin and Katz 2009; Wyatt and Hecker 2006; Zhou 2005). While many aspects of such a schooled and knowledge society have been analyzed, a crucial phenomenon has remained surprisingly implicit – the expansion of, broadly speaking, knowledge-intensive work and related personnel.

I view the large-scale knowledge-based transformation of economies – as a consequence of the growing importance of education and science in modern societies that emerged at the end of the 20th and the beginning of the 21st century – as having strong implications on job content across economic sectors and countries. More precisely, this study focuses on the expansion of innovation-related personnel composed of "professionals engaged in the conception or creation of new knowledge, products, processes, methods and systems" (UNESCO 2015: 741). This R&D-oriented job description includes but moves beyond academic research and instead comprises a wide range of occupational tasks from (non) governmental sites to universities and for-profit corporations. All tasks reported here involve originality, creativity, and uncertainty as well as higher-order thinking commonly performed in a systematic and reproducible fashion. Such tasks cut across traditional categories of economic sectors, industries and even educational degrees, yet share a designation as research-related, non-routine, novelty-oriented and open-ended job content that explicitly includes aspects of basic, applied and experimental research (OECD 2015).

Obscured by the omnipresence of the knowledge economy discourse, we know surprisingly little about the empirical evolution and driving factors of this knowledge-creating segment of contemporary job markets in a longitudinal and cross-national perspective. This article empirically revisits the knowledge economy by examining global trends in the evolution of R&D capacity and their underlying causes. Analyses draw on cross-national data on R&D-related personnel for the period 1980 to 2015, both aggregated and by sector (academic vs. corporate) for up to N = 82 countries (OECD 2020). I apply regression models with country panels of various sizes in order to test a number of hypotheses about potential determinants of research expansion. Drawing on several theoretical perspectives, these determinants reflect educational, economic, political and institutional arguments.

Results show a striking increase in the number of knowledge personnel worldwide with only a few countries reporting decline. On average, OECD countries more than tripled their R&D personnel since the 1980s, while non-OECD countries see their number of professional knowledge workers doubling since the mid-1990s.

Panel analyses for the post-1990 period suggest that educational predictors (especially public higher education governance and tertiary enrolment) show strong effects, yet economic factors, i.e., funding and GDP, also matter. Expansion is also strongest in countries with strong linkages to global institutional networks, particularly in non-OECD countries. Additional sector-specific analyses show that both corporate and academic expansion are mainly associated with educational and economic factors as well as global embeddedness.

I argue that these findings indicate the global growth of a knowledge-intensive occupational field, which cuts across sectors and countries and which is becoming a central pillar of globally-embedded (although not necessarily liberal) schooled societies if aided by strong state support.

The Expansion of Education and the Transformation of Work

Education and science systems worldwide have seen dramatic expansion in recent decades, while economies and labor markets are being transformed toward a stronger premium on non-material goods, knowledge-intensive skills and non-routine tasks. In this section, I review the development of these twin trends and elaborate on how these are intertwined.

The Expansion of Education and Science

Education (particularly higher education) and science systems around the world have been undergoing a massive expansion, both historically and more recently. Novel academic (sub)disciplines and related faculty flourish and fuse, differentiate and establish themselves at a regular pace (Ben-David and Collins 1966; Brint et al. 2009; Frank and Gabler 2006; Wotipka et al. 2018). Higher education enrolment is experiencing unprecedented momentum worldwide, particularly in low- and middle-income countries, now accounting for a third of the global cohort with an increasing number of students continuing to the graduate level (Schofer and Meyer 2005; OECD 2015a; Trow 1999; UIS 2019).

National scientific planning and policy has become a universal feature (Finnemore 1993) as have non-governmental national and international science associations that promote and protect the scientific cause (Schofer 1997). In the same vein, despite persistent disparities, government expenditures on higher education and R&D grow steadily in virtually all countries as do non-governmental and industry investments in research (EC 2018; OECD 2020). Such favorable conditions have translated into unprecedented levels of scientific output, sometimes described as "global mega science" (Powell et al. 2017) with the modern research university representing the pinnacle of the knowledge society (see also Bornmann and Mutz 2015; Välimaa and Hoffman 2008).

Driven by a variety of political, cultural, social and technological factors, science increasingly resembles a world scientific system (Drori et al. 2003; Schofer, Ramirez and Meyer 2020). Concomitant with such expansive integration, the sites of research production multiply beyond the modern research university now including extra-university institutes, hospitals, governments, international organizations and, importantly, a growing industry capacity for R&D (Zapp 2017; Etzkowitz and Leydesdorff 2000; Kaiserfeld 2013). Such knowledge expansion and organizational diversification has implications for our understanding of how work is performed in modern economies, an argument to which I now turn.

The Transformation of Work

The educational and scientific revolution of the 20th century has had measurable consequences beyond the direct observation of expansive enrolment, organizational infrastructure and policy relevance. A distinct set of important arguments refers to the more complex relationship between (higher) education, science and their effects on labor markets.

Since the late 1990s, policy and scholarly debates have stressed the advent of the knowledge-based economy, sometimes equated to the service or quaternary sector (e.g. OECD 1996; WB 2003). This shift would entail the educational and neuro-cognitive transformation of work and the emerging educated workplace with life-long learning becoming a key in continuously upgrading skills (Zapp and Dahmen 2017; Baker 2009), while predicting the end of the post-industrial era and the onset of rapid obsolescence (Powell and Snellman 2004).

To a large degree, these diagnoses are confronted with a daunting empirical challenge as most existing data do not adequately capture job content, let alone daily tasks and activities. Instead, conventional reporting assigns labor market segments to produced outputs to facilitate cross-national comparability (see Schofer, Ramirez and Meyer 2020; WB 2019 for a discussion). What we know is that there seems to be an increasing premium on skills and, particularly, higher-order thinking skills. Zhou (2005), for example, finds that occupation status (or prestige) is increasingly based on social recognition of how much the work content is related to the use of abstract reasoning and authoritative theoretical knowledge in addressing the fundamental nature of things. Greater amounts of these qualities are associated with higher status and might also help explain the co-evolution of educational attainment and wage structure in the United States through the 20th century (Goldin and Katz 2009). Similarly, the so-called Oxford Study on the Future of Employment (Frey and Osborne 2013) sees "knowledge work" as a growing segment of the U.S. labor market and – provided it depends on creative and social intelligence – as largely immune to computerization. Recent research also corroborates the assumption that the expansion of higher education and the growth of the economy and particularly the service sector (despite its heterogeneity) are tightly linked (Schofer, Ramirez and Meyer 2020).

However, while these and other studies point to important changes in value creation, occupational and credential structure as well as skill formation, they usually rely on country-case studies or focus on particular sectors and industries instead of depicting the transformation as a global trend that, in addition, cuts across various economic segments. These studies also present cross-sectional or short-range perspectives while largely ignoring the long-term trends. Most importantly, these contributions add little to our understanding of the changing job content, that is, the actual daily activities and tasks. The following section explores the complexities of occupational transformation and presents hypotheses that outline the expansion of the knowledge economy as a multidimensional phenomenon.

Explaining the Expansion of Professional Research

With the quasi-omnipresence of scientific knowledge, research and development in modern economies, it is reasonable to expect the expansion of knowledge-intensive activities and associated personnel to occur everywhere in the world – even with such an expansion occurring at a varying pace. There is, however, little theorization about the causes of this process. I argue that such an expansion is mainly driven by a set of factors which are commonly associated with a (neo)liberal model of society with higher education expansion at its core. In addition, this broad institutional set includes economic and political determinants as well as factors of global embeddedness. These key institutions are, in theory, all conducive to facilitating the large-scale change described as the "knowledge economy". The goal of this study is to gauge the extent to which these determinants matter and whether they play out distinctively across sectors and country groups. This section reviews theoretical assumptions about the knowledge economy and builds hypotheses that inform my empirical analysis.

Educational Factors: Higher Education Expansion, Governance and Professionalization

Here, I draw attention to a first set of causes that reflect educational mechanisms and, more specifically, mechanisms related to the size, governance and professionalization infrastructure of the higher education system.

Higher Education Expansion

First, I rely on recent advances in the sociology of education where traditional arguments of simple human capital and demand-supply logics have been questioned. In these arguments, research expansion is not just determined by demographic pressure and related social mobility and stratification trends (the "pipeline logic") (Baker 2009; Collins 1979). It is true that with more people being certified to enter higher levels of academic training, they are likely do so and the recent surge in mass-absorbing private higher education institutions worldwide has been explained by an unprecedented student demand otherwise not met by extant public institutions (Buckner and Zapp 2021). However, the pipeline and human capital argument can be extended in that academically-trained employees do not simply enter the labor market filling vacant positions which are variably described as R&D-related. Rather, these schooled individuals themselves transform job content instead of merely responding to market demand (Baker 2009). The science-driven rationalization of society and the economy reconceptualizes formerly noneconomic activities such as child care, health services, education and legal services as well as philanthropy as economic and monetarized activities (Schofer, Ramirez and Meyer 2020). Equipped with the analytical toolkit of academic training including creative, analytical, methodical, abstract as well as critical thinking skills, a growing number of graduates turn extant task profiles into opportunities for the creation of novel processes. Instead of reproducing routine, the reproducibility of knowledge creation becomes the routine and is increasingly associated with much prestige (Frey and Osborne 2013; Zhou 2005).

H1a: Expansion of R&D personnel is stronger in countries with high postsecondary enrolment.

Governance

Second, I emphasize that the expansion of knowledge-intensive sectors requires strong political support, not only financial but also in a regulatory sense. The argument is somewhat complicated by the fact that the extent to which governments maintain control over the higher education system and innovation industries can, in theory, have either positive or detrimental effects on its expansion. While most state-dependent systems feature cost-free studying, many countries with strong public oversight also restrict access to specific academic fields, either through a quota or *numerus clausus* (e.g. for medicine in Ireland or Germany) or competitive national exams (as in the case of admission to the *grandes écoles* in France). By contrast, private systems are believed to produce more autonomous universities making them more successful at – and indeed in need of – creating linkages to industry research and in acquiring external funding, which might make them more resilient in times of stagnating public funding (e.g. Labaree 2017; Schofer and Meyer 2005). At the same time, most higher education and science systems in the world are heavily state-backed and a change in science policy can deeply impact the trajectory of R&D.

Importantly, the argument extends beyond higher education. For example, the launch of large-scale theme-related research programs can sustainably alter the fabric of research (Zapp, Helgetun and Powell 2018). Both historically and in the more recent period, strong state intervention (e.g. space exploration in the U.S. and Soviet Union) and a favorable regulatory framework (e.g. genetics in China) creates the critical mass and necessary freedom to boost innovations which would otherwise hardly see the light of day. Similar efforts in research on cancer, climate change, educational assessment or the recent Covid-19 pandemic are also examples of "commissioned" agendas with countries as diverse as Singapore, Taiwan and South Korea proving that tight governance, strong public oversight of higher education systems and industry regulation do not necessarily mean a trade-off *vis-à-vis* dynamic innovation (Cantwell and Mathies 2012; Mok 2010; Wang 2018). Following this latter argument, I posit that the growth of the knowledge economy shows higher rates in countries with higher degrees of steering capacity as reflected in strong public higher education systems.

H1b: Expansion of R&D personnel is stronger in countries with strong public higher education systems.

Professionalization

More than half a century ago, Wilensky (1964) noted wide-spread professionalization based on the creation, certification and protection of specific stocks of knowledge. Obviously, knowledge-based specialization is a key attribute of R&D. Disciplinary and professional associations and related journals not only fuel much internal boundary-drawing and differentiation in academia, they also establish professional identity, certify membership and signal legitimacy across industries and labor market segments (Meyer 1977; Brint 1994; Abbott 1988). While such professionalization is usually analyzed in terms of specialization benefits, there are wider consequences to the proliferation of university-trained professionals in that they systematically rationalize – applying analytical, systematic and replicable research-like methods – in every domain in which they emerge (Drori et al. 2003; Frank and Meyer 2020).

Although the data used in this study captures a wide range of knowledge-creating activities beyond traditional intra-mural or PhD-based tasks, academic training infrastructure capacity can be seen as the prerequisite for the expansion of knowledge-intensive personnel as it equips future employees with the analytical and creative skills thought to be at the core of the knowledge economy. As Ben-David (1971) and Brint (1994) noted, the institutionalization of the American graduate school laid the foundation stone for the subsequent professionalization of generations of researchers of which only very few (can) remain in academia (see also Fernandez et al. 2021 for a recent analysis).

H1c: Expansion of R&D personnel, particularly academic research, is stronger in countries with higher numbers of doctorate-granting institutions relative to the size of the higher education system.

Economic Arguments: Development and Investments

Prevailing arguments hold that R&D is an important engine of economic growth and/or a response to growing societal complexity. In its classical formula, it resembles the tenets of human capital and differentiation theories (Schultz 1971; Becker 1994). In such a utilitarian "science for development" policy model, science is understood as a national, systemically-planned and economically viable tool to foster progress (Drori et al. 2003).

More recently, such instrumental ideas of research creating spillover effects in the guise of academia-industry collaborations, patents, university spinoffs and the like have become part and parcel of national and international science policy discourses (see, for example, Etzkowitz and Leydesdorff 2000; Slaughter and Rhoades 2004). In this perspective, confronted with increasing complexity and differentiation in society and markets, academia adopts industry logics, whereas industry incorporates those from academia.

It is important to note that this argument is complicated by the possibility of reverse or two-way causality if it is assumed that R&D is mostly occurring in higher education. For instance, Schofer, Ramirez and Meyer (2020) find that higher education expansion is associated with expanded economic activity overall, particularly in the service sector (see also Valero and Van Reenen 2019). In these accounts, the specific link between economic growth, wealth, education and innovation is specified *via* the strength of the service sector. However, the service sector is highly heterogeneous and crudely measured including both very high and low-skill jobs, often assigned to sectors of primary activity instead of based on task profiles. Additionally, by definition, the OECD based on the Frascati methodology collects data across sectors (see below). As this study is interested in R&D as a general feature of modern economies across sectors and industries, such unidirectional assumptions are of limited use. As a consequence, I formulate the hypothesis based on broader causal relationships.[1]

H2a: Expansion of R&D personnel is stronger in economically-developed countries.

Related arguments hold that R&D expansion is a function of investments into knowledge infrastructure. For academic R&D expansion, this line of explanation echoes so-called "externalist" arguments from the sociology of science whereby the growth of science is primarily determined by conditions outside of academia, notably funding (Cantwell and Mathies 2012; Elzinga 2012). Following this logic, richer countries dedicate more resources to their training and research systems, and can accommodate larger numbers of researchers who in turn, enter industry and transform jobs and labor markets. Large government-led research programs as

[1] Including economic sectors in alternative models does not change results with the service sector (as a share of GDP) being positive yet not significant (Appendix B).

well as “excellence initiatives” also channel vast funds to both the academic and, indirectly, the corporate sector not only altering the course of scholarly thinking but vastly increasing the personnel base in the particular field (Zapp, Marques and-Powell 2018). In addition, a growing number of research councils (including the European Research Council) have designated funding streams targeting university-industry collaboration in research, development and training (e.g. the EU’s Marie-Curie Skłodowska Programme). In general, much of the OECD discourse on science expansion, for example, pushes for higher investments in national innovation systems through R&D expenditures (OECD 2018). If these R&D funds are channeled toward the higher education system, this functionalist discourse reflects the prevailing idea of universities as having a “third mission” – in technology transfer and wealth creation.[2]

H2b: Expansion of R&D personnel is stronger in countries with higher levels of research and development expenditures.

Democracy

Historically, authoritarian regimes have had little interest in an educated citizenry (e.g. Khmer Rouge in Cambodia or ‘bantu education’ under apartheid South Africa) and science grew more rapidly in democratic regimes (Ben-David 1971; Merton 1968). For example, highly regulated admission and limited access had contained the growth of higher education in communist countries for decades (Ramirez 2002; Baker et al. 2004). Until the present day, universities continue to be the cradle of critical thought and resistance across the globe. They become subject to surveillance and oppression in illiberal regimes and even in liberal polities may suffer reputational damage and legitimacy loss due to state repression (Schofer, Lerch and Meyer 2018). At the same time, industrial R&D, especially of the applied kind, flourishes everywhere and even in states such as China that are otherwise oppressive. However, with private property (including intellectual property) and return on investment being more strongly protected in liberal polities, I form the hypothesis in its traditional variant.

H3: Expansion of R&D personnel is stronger in democratic polities.

Global Embeddedness

Science and industrial R&D have always been highly internationalized professional fields and have become more so in recent decades with the growing mobility of researchers and the highly-skilled as well as the proliferation of digital media and international scientific and professional associations (Schofer 1997; Heilbron 2014). Here, science and R&D are understood both as a commodity and a global policy

[2] One might suspect that some countries channel funds to R&D through higher education streams, yet longitudinal data on higher education expenditures are notoriously unreliable. Including higher education expenditures does not change results and the variable is negative and not significant (see Appendix B, electronic supplementary material). Similarly, R&D might increase with higher levels of foreign direct investment, which are, however, measured in aggregation. Models including FDI as additional predictors show a negative and non–significant association (available upon request).

model of national and, more recently, global human development (Drori et al. 2003; Buckner 2017).

I focus on international science and professional associations as promoters of research and innovation as a means to foster progress. Membership to international organizations has often been treated as a "receptor site" for global institutional change (Frank et al. 2000; Lerch 2019). Previous research on the expansion of secondary and post-secondary education enrolment, for example, has found strong support for the role of international discourses in such expansion (Schofer and Meyer 2005). The worldwide proliferation of science bureaucracies is also strongly associated with the work of international organizations like UNESCO (Finnemore 1993) as is the expansion of women faculty (Wotipka et al. 2018). These globally-operating associations advocate science and research and advise states and corporations on how to transform their internal policies. Linkage to these should lead to an accelerated uptake of R&D activities.

H4: Expansion of R&D personnel is stronger in countries with strong linkages to international science and professional associations.

Methodology

Data

Dependent Variables

Data on personnel are provided by OECD and UIS/UNESCO and rely on surveys in accordance with the Frascati Manual (OECD 2015). For decades, the Frascati Manual has set forth the methodology and standards for collecting R&D data and these standards are widely used by countries worldwide as well as the UN and the EU (Godin 2005).

The Frascati Manual defines research and experimental development as "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge" (OECD 2015b: 28). R&D workforce, here, is defined as "professionals engaged in the conception or creation of new knowledge (who conduct research and improve or develop concepts, theories, models, techniques instrumentation, software or operational methods)" (OECD 2015b).

It is important to emphasize that being counted as R&D personnel does not depend on a person's educational degree. Frascati statistics reflect the actual activities more than the formal qualification. Personnel defined as R&D-related can, in theory, hold any degree on UNESCO´s International Standard Classification of Educational Degrees (i.e. levels 1–8).

The Frascati Manual distinguishes between three forms of research including basic research, applied research and experimental development. Analyses presented in this study do not distinguish between these three forms since such fine-grained data is mostly incomplete cross-nationally, yet all three forms of research include the five key criteria of R&D: "novelty, creativity, uncertainty, systematic, reproducibility and transferability" (OECD 2015b: 46f).

The heterogeneity of R&D activities but also the internal complexity of many private enterprises makes it difficult to classify R&D personnel according to traditional economic sectors such as agriculture, manufacturing or services. As these sectors are themselves highly heterogeneous (especially the service sector), the Frascati Manual prefers to group activities according to a combination of either the main economic activity, the industry orientation, the product field or the knowledge domain. For example, research on improving the use of pesticides might still be classified as an agricultural product field. In general, private R&D activities can play out in any type of conventional sector or corporate setting (OECD 2015b). At the same time, R&D data in higher education is collected based on traditional disciplinary boundaries like natural sciences, engineering, medicine, agriculture, social sciences, and the humanities.

To provide more examples of how Frascati definitions play out in data collection, consider the following cases. For example, an oral history project conducted by a religious charity would be classified as being basic research in the field of humanities, performed by a non-governmental, non-profit organization. Also included would be a doctoral student in a public university hospital who, besides getting training and providing health care, is explicitly involved in scientific R&D efforts. Other examples include the development of pilot plants, prototypes and research-based industrial design and engineering (OECD 2015b).

Consider also examples of what is excluded from R&D activities. These describe, for instance, the use of traditional knowledge in managing crops, the routine development of products based on traditional knowledge, the storage and communication of traditional knowledge as well as religious or cultural practices (OECD 2015b). For the industry sector, it also excludes, among others, after-sales service, patent and license work, routine tests and data collection.

The advantage of the Frascati method is that it captures precise job content in daily tasks and concrete activities. This is unlike other studies where only official job descriptions, educational credentials, earnings and sectoral aggregations are recorded (see, for example, Goldin and Katz 2009 or Frey and Osborne 2013). This micro-perspective provides a more accurate estimate of the "knowledge turn" in job markets.

At the same time, the OECD acknowledges that data collection is challenging due to overlapping activities, functions and sectors. Fully capturing all R&D-related activities may well be impossible, leaving the true extent of R&D expansion underestimated. This is especially true of the service sector (e.g. banking and finance) where blurry job activities are prone to surveying problems. Further, actual data collection is conducted at local institutional and national levels and then reported to the OECD. The OECD cannot ascertain the degree to which the data is accurate and complete. Despite these difficulties, R&D personnel (and expenditure) data based on the Frascati framework is the most reliable source available to date and has remained largely consistent in methodology since the 1980s.

Analyses use R&D personnel per 1,000 employed at full-time equivalent (FTE) as the main dependent variable (OECD 2019; UNESCO 2019) comprising all sectors – in governmental and non-governmental, higher education and for-profit/corporate R&D.[3] FTE measures are especially useful for international comparisons. One FTE represents a one person-year. For example, a person who normally spends 30% of her time on R&D and the remaining time on other activities (such as teaching, university administration and student counseling) should be considered as a 0.3 FTE (OECD 2015b).[4]

In addition to overall R&D personnel, analyses use two specific sectors as additional dependent variables, i.e. corporate R&D and academic or higher education R&D. I chose these two particular sectors for three reasons. First, data availability is greatest for these two sectors as compared to all others. Second, empirically, these two sectors account for the largest share of R&D personnel; in many countries, they account for over 70%, in some even 75% of all R&D personnel. In addition, scholarship has mostly focused on these two sectors. While this does not mean that the other sectors are to be neglected, I argue that the most pressing questions revolve around industry and higher education. Theoretically, one may argue that academic and industrial R&D represent very distinct spheres, with each requiring a different set of predictors. At the same time, they largely overlap in their embedding in wider society. For example, no higher education system could possibly absorb all those graduates through academic position. Further, both the academic and the corporate sector benefit from public support, either through funding, favorable legislation or (free or subsidized) education.

All outcome variables are measured at 5-year intervals. Data coverage is limited for the pre-1990 period, especially for non-OECD countries and is further complicated by major political changes and associated reporting practices (as in post-Soviet countries). For the dependent variable, prior to 1990, sample size is N = 35 countries. For the 1990–2015 period, sample size is N = 82 countries, however, some countries are missing data for important predictors. I therefore run models with varying sample sizes.

[3] An alternative approach would consist in using an annual change score as the DV. However, change is accounted for by using time–fixed effects (see below).

[4] In detail, the measure is computed as persons employed in the statistical unit (FTE) who actually contributed to intramural R&D in the reference year, weighted for the share of the working time devoted to R&D; 100% =1 (FTE_{int}) and external R&D personnel (including unpaid personnel) (FTE) who actually contributed to intramural R&D in the reference year, weighted for the share of the working time devoted to R&D, 100% =1 (FTE_{ext}). Adding up these two variables: Total R&D personnel (FTE) = FTE_{int} + FTE_{ext}

Predictors

Educational Predictors

I use time-varying tertiary enrolment rates, both male and female (UIS 2019), at *t*–5 assuming a lagged cohort effect. To measure state control, I computed a time-dependent share of public versus private universities (ISCED +5) based on the International Association of Universities' (IAU) World Higher Education Database of 17,129 universities (WHED 2017).[5] The public-private distinction is based on the standard definition of legal status of higher education institutions. I assume that a higher share of public institutions reflects stronger state control of the higher education system. In order to measure professionalization via doctoral training capacity, I compute the share of doctorate-granting institutions by country based on IAU's WHED (2017). This is a time-varying variable based on various editions of the WHED and the International Handbook of Universities, measured at *t*–5. Both datasets contain information on academic structure including universities' graduate programs. Alternately, I measured doctoral training capacity as a per capita measure and with varying lags (e.g. *t*–10), yet results show no changes (available upon request).

Economic Predictors

I control for country-level economic development and, by implication, social differentiation using a time-varying measure of gross national income per capita, from the World Bank (2019; logged to reduce skewness). I use time-dependent data on R&D expenditures as a percentage of GNI (UIS 2019; OECD 2019). Gross domestic expenditure on R&D (GERD) includes expenditure on research and development by business enterprises, higher education institutions, as well as government and private non-profit organizations. As I assume some time lag between input (expenditures) and output (expansion of personnel), the models include data for both indicators measured five years prior (t–5) to the dependent variable.

Political Predictors

I use a measure of a country's level of democracy from the Polity IV Index (Marshall and Jaggers 2017), which ranges from highly autocratic (–10) to highly democratic (10). I account for changes during the observation period by using the Polity Score as a time-varying measure.

Global Embeddedness Predictors

The Union of International Associations provides longitudinal data on national membership ties to international science and professional associations gleaned from the Yearbook of International Associations. The variable is logged.

Descriptive statistics for all variables are presented in Table 1.

[5] The measure is (count private HE/(count private HE + count public HE). See Zapp and Lerch (2020) for more details on IAU data.

Table 1 Sample description

	Obs	Mean	SD	Min	Max
FTE R&D per 1000 employed	480	3.50	3.61	0.00	16.87
FTE R&D per 1000 employed, corporate sector	390	1.56	2.17	0.00	10.85
FTE R&D per 1000 employed, higher education sector	456	0.58	0.64	0.00	3.35
Tertiary enrolment t–5	438	38.11	25.74	0.00	103.00
Public system (private/public ratio)	480	0.36	0.26	0.00	0.92
PhD training capacity t–5	480	0.49	0.25	0.00	1.00
GNI/ cap (log)	480	3.75	0.68	2.09	4.97
R&D expenditures t–5	480	1.69	2.94	0.00	16.48
Democracy score	480	0.70	0.46	– 10	10
Science INGO membership (log)	480	1.60	0.40	0.00	2.02

Methods

R&D capacity expansion is analyzed using panel regression models with time-fixed effects as the DV consists in one observation per year with countries producing variation for each observation. The literature suggests a variety of models to analyze cross-national and longitudinal data including OLS regression with panel corrected standard errors, fixed and random effects, models addressing serial correlation (AR1), and models with cluster-robust standard errors (e.g., Beck and Katz 2011; Plümper, Troeger and Manow 2005). There has also been much innovation in estimating dynamic panel models (accounting for time-series effects; see Baltagi 2008) and I conduct a model accounting for growth in the prior period in which each panel includes a dependent variable measured at time *t*, and the lagged dependent variables measured five years earlier (*t*–5). Outputs in Appendix B (electronic supplementary material) show that results are consistent across all these different modeling approaches.

Additional Collinearity and Robustness Checks

I observe one problematic correlation between tertiary enrolment and gross national income ($r^2 = 0.66$; see Appendix Table B1, supplementary material) and run models without GNI and with enrolment and GNI as an interaction. As results show little variation, I decided to keep predictors as separate variables in the models since they reflect distinct theoretical arguments.

Finally, although there are no outliers in the statistical sense (based on a box-plot examination), I also run a model without the top three minimum and maximum observations in the sample. Results show only minor changes (see Appendix Table B2, electronic supplementary material).

Results: The Global Expansion of Knowledge Work

The following section presents descriptive data on expansion trends in general, and by groups and sectors in particular before results from the regression analyses are reported.

Expansion Trends

In the past four decades, the expansion of R&D capacity has seen considerable momentum worldwide growing from 3 FTE to 5.4 FTE per 1,000 employed in the period 1990–2015 (Figure 1). This growth is particularly strong in OECD countries where a first boost took place in the late 1980s and a second in the mid-1990s. In the period 1980–2015, the number of R&D-related jobs in OECD countries more than tripled (from slightly below 3 to just below 9 FTE). Over the same period, non-OECD countries doubled their R&D personnel, with their increase also beginning in the mid-1990s.

While the expansive trend can be found in virtually all regions worldwide, some countries show stronger growth patterns than others and a small group of countries even report shrinking R&D personnel. Figure 2 presents the geographical variation in the changes of research capacity for the period 1990–2015 divided by four percentiles.

The strongest expansion can be found in many European countries as well as East and South East Asia and Oceania – particularly in Singapore, Denmark, and South Korea – which increased their R&D personnel by a factor of ten and more. Middle

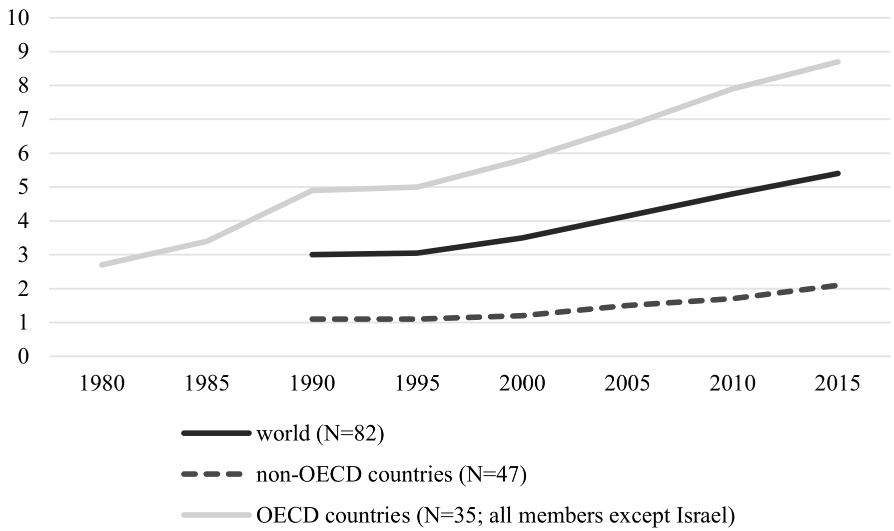

Fig. 1 The expansion of R&D personnel in OECD and non-OECD countries, 1980–2015 (FTE per 1000 employed; OECD 2019; UNESCO 2019)

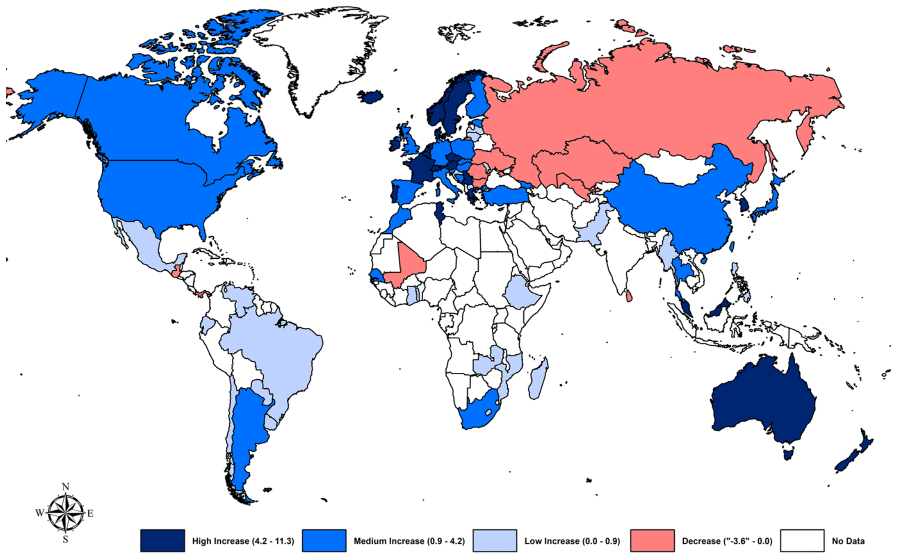

Fig. 2 Change in R&D personnel worldwide, 1990–2015 (FTE per 1000 employed; OECD 2019; UNESCO 2019)

range increases took place in China, North America, Argentina and some European countries, while many Latin American, African and some Asian countries report smaller growth rates.

As a striking finding, a group of N = 14 countries report decreases in R&D capacity. For example, post-Communist Russia, Ukraine and Bulgaria show a 40% decrease during the observation period[6], probably explained by significant emigration after 1990. The Gambia, Mali and Sri Lanka are the only African and Southern Asian countries with drops in knowledge personnel. Panama and Guatemala are the only Latin American countries to also report slight decreases (see Appendix A (electronic supplementary material) for country data).

Table 2 specifies these findings with annual growth rates for R&D personnel by period, country group, and sector. Overall personnel capacity increased by 3% in both OECD and non-OECD countries and is slightly stronger in the 1990s compared to the last 15 years.

Within the OECD, expansion occurs at a rate of 2.6%, whereas non-OECD countries expanded by 1.9%. However, while growth slows down in the OECD group in the more recent period, countries outside of the OECD catch up showing the same rate (2.6%) in the post-2000 period. As seen above, some countries reflect a particular phenomenon of contraction. Removing these outliers (N = 3) from the sample increases the growth rate considerably, up from 3.1 to 4.5%.

[6] As the strongest decreases can be found in post–Soviet and post–Communist countries, I ran additional models with respective dummies, yet results show a positive instead of a negative effect even after controlling for different periods, e.g. 1990s vs. post–2000s (see Table B4 in the Appendix, electronic supplementary material).

Table 2 Annual growth rates for R&D personnel by period, country group, sector, gender (%) (OECD 2019; UNESCO 2019)

	(%) 1990–2015	(%) 1990–2000	(%) 2000–2015	N
Country group				
All	2.4	1.25	3.25	82
OECD	2.2	1.7	2.7	35
Non-OECD countries	2.6	0.8	3.8	47
All without outliers	4.0	4.5	3.5	58
Specific sectors				
Higher education	1.1	1.1 (2.5)*	1.2 (1.8)	76
Private for-profit	3.5	3.8 (4.9)	3.3 (3.2)	76

*Without outlier observations (> – 2.0 decrease) in parentheses

Comparing sectors, expansion is primarily carried by the corporate sector where growth rates surpass higher education by more than a factor of three (at 3.5 and 1.1 respectively) although a slight convergence takes place in the more recent period and when outliers are removed from the sample.

What Drives Research and Development Capacity?

Turning to the regression analyses, models present first general expansion and then sector-specific estimates. For general expansion, I present a series of models that include predictors one by one. Model 1 includes only educational predictors, Model 2 economic predictors and Model 3 and 4 include political and embeddedness factors respectively. Model 5 includes all variables. Coefficients remain consistent throughout all models although effect size varies pointing to some degree of collinearity (see also Table B1 in the Appendix, electronic supplementary material). Higher enrolment rates and a higher share of public universities are associated with R&D increase. The same pattern can be found for higher levels of economic development, funding and global embeddedness. Interestingly, Models 1 and 2 show larger values for explained variance ($R^2 = .61$ and .72) as compared to Models 3 and 4, also supported by significant time effects in these models. Model 5 includes all variables. As before, educational and global embeddedness factors matter most. For example, growth in higher education enrolment (*H1a*) (by one standard deviation) is associated with an increase in R&D personnel by .05 standard deviations. Importantly, a strongly state-backed higher education system emerges as the most important predictor (*H1b*; B = 2.36), while doctoral training (*H1c*) shows no effect. Linkages to the global science associational network are also strongly correlated with R&D expansion, yet a democratic polity has no effect.

Economic development and R&D expenditures (*H2a & b*) are both positively and significantly correlated with R&D growth. This supports arguments that the

Table 3 Panel regression estimates for overall R&D personnel expansion, 1990–2015 (FTE per 1000 employed)

	Model 1	Model 2	Model 3	Model 4	Model 5
Educational factors					
Tertiary enrolment t–5	0.11***				0.05***
	(.005)				(.00)
Public HE system	2.91***				2.36***
	(.44)				(.33)
Doctoral training capacity t–5	−0.59				−0.24
	(.46)				(.34)
Economic factors					
GNI/ cap (log)		1.12***			0.71***
		(.16)			(.20)
R&D expenditures t–5		0.73***			0.56***
		(.04)			(.03)
Political factors					
Democracy score			0.24		0.20
			(.34)		(.21)
Global embeddedness					
Science INGO membership				0.91***	0.84**
				(.34)	(.21)
1990	0.23	0.65	1.96***	2.20***	0.67*
	(.40)	(.31)	(.53)	(.48)	(.38)
1995	0.12	0.65	2.02***	1.90***	0.59*
	(.39)	(.31)	(.53)	(.48)	(.29)
2000	-0.06	0.63	1.71***	1.53***	0.45
	(.37)	(.30)	(.52)	(.48)	(.28)
2005	-0.37	0.38	1.26***	1.05	0.15
	(.37)	(.30)	(.52)	(.48)	(.27)
2010	-0.34	0.17	0.60	0.54	0.05
	(.36)	(.30)	(.52)	(.48)	(.27)
Constant	0.74*	−5.37	3.05	−2.45	−2.80***
	(.43)	(.63)	(.45)	(.65)	(.67)
N (country-years)	438	438	438	438	438
R-square	.61	.72	.14	.29	.80
Countries	73	73	73	73	73

Standard errors in parentheses

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$, $^{+}p < 0.10$

knowledge economy is also a high-income country and high-investment phenomenon (Table 3).

Turning to specific sectors, Models 6 and 7 present separate analyses for higher education and industry R&D personnel (Table 4). Starting with Model 6, changes in higher education R&D is driven by student enrolment. Further, public systems are again much more likely to expand as are those with a larger doctoral training capacity. Innovation systems more strongly linked to the global associational network also

Table 4 Panel regression estimates for R&D personnel expansion by sector, 1990–2015 (FTE per 1000 employed)

	Model 6 Higher education	Model 7 Corporate
Educational factors		
Tertiary enrolment t–5	.02*** (.00)	.02*** (.00)
Public HE system	.63*** (.11)	.95*** (.22)
PhD training capacity t–5	.23* (.11)	–.65*** (.23)
Economic factors		
GNI/ cap (log)	–.18** (.07)	.32** (.13)
R&D expenditures t–5	–.03** (.01)	.47*** (.02)
Political factors		
Democracy score	.04 (.07)	–.07 (.14)
Global embeddedness		
Science INGO membership	.28** (.09)	.37* (.17)
1990	$.19^{+}$ (.10)	.90*** (.20)
1995	.15 (.10)	.81*** (.19)
2000	.09 (.09)	.64*** (.18)
2005	.02 (.09)	.37*** (.18)
2010	.02 (.09)	.15*** (.17)
Constant	.29 (.23)	–1.50*** (.44)
N (country-years)	414	414
R-square	.35	.77
Countries	69	69

Standard errors in parentheses

***$p<0.001$, **$p<0.01$, *$p<0.05$, $^{+}p<0.10$

expand more strongly. Interestingly, growth in academic R&D personnel is negatively associated with GNI and R&D expenditures (*H2a & 2b*).

By contrast, knowledge-intensive jobs in the industry sector are more likely to flourish in economically more developed countries and in those countries where the levels of R&D expenditure are higher. Importantly, tertiary enrolment also contributes to private R&D and the public nature of the higher education system is, again, the strongest predictor. At the same time, doctoral training capacity is negatively associated with private R&D expansion suggesting that the private knowledge economy is largely decoupled from academic training. Membership in international professional and scientific associations also correlates with expansion, even stronger in the corporate than the academic sector. As in Model 5, democracy has no effect on this sector-specific R&D growth.

As shown above in Figure 1 and Table 2, different temporal patterns can be observed for OECD and non-OECD countries. The two final models investigate whether predictors operate differently across these two country groups (Table 5). Indeed, some interesting differences can be identified. Educational predictors, namely tertiary enrolment and public governance show stronger associations with R&D expansion outside the OECD, while doctoral infrastructure exits

Table 5 Panel regression estimates for overall R&D personnel expansion, by country group, 1990–2015 (FTE per 1000 employed)

	Model 8 OECD	Model 9 Non-OECD
Educational factors		
Tertiary enrolment t–5	.05*** (.01)	.36*** (.00)
Public HE system	1.61* (.74)	2.07*** (.34)
Doctoral training capacity t–5	−.32 (.81)	.41 (.34)
Economic factors		
GNI/ cap (log)	3.33*** (.89)	.19 (.20)
R&D expenditures t–5	.41*** (.07)	1.18*** (.22)
Political factors		
Democracy score	.40 (1.44)	.26 (.18)
Global embeddedness		
Science INGO membership	−5.36** (1.91)	1.02*** (.24)
1990	1.08 (.72)	.31 (.30)
1995	.81 (.63)	.33 (.30)
2000	.92 (.58)	.18 (.29)
2005	.21 (.54)	.04 (.28)
2010	−.00 (.50)	−.00 (.28)
Constant	−2.77* (4.5)	−1.45* (.71)
N (country-years)	166	227
R-square	0.69	0.58
Countries	31	50

Standard errors in parentheses

*** $p<0.001$, ** $p<0.01$, * $p<0.05$, + $p<0.10$

both models (while being positive in non-OECD countries). Plausibly, the economic development measure is higher in OECD countries, yet investments play a stronger role in non-OECD countries. Interestingly, while democracy has no effect both for OECD and non-OECD countries, links to world society turn out to be highly negative inside the OECD, yet positive outside the OECD.

Discussion: Bringing the State Back into the Schooled Society?

Much of the discourse on the knowledge society has stressed that the constant creation of new knowledge is becoming a fundamental feature of late modern societies in transforming the economy, labor markets and other domains of public life. While this debate has been held with both enthusiasm and skepticism, it has also been held in the absence of solid empirical data that provides insights into the knowledge economy as a historical and worldwide phenomenon that is strongly reflected in the changing nature of work.

Analyses presented in this article illustrate a notable increase in the number of knowledge personnel worldwide with only a few countries reporting a decline. Strikingly, the strongest contraction can be found in some post-communist countries, namely Russia, Bulgaria and Ukraine as well as Uzbekistan, Romania and Kazakhstan. As the observation period for these countries begins in 1990, their shrinking R&D capacity very likely reflects massive emigration waves. A well-educated highly-skilled workforce, particularly in fields such as science, technology and engineering, took an opportunity outside their then-struggling economies once such mobility was granted (Baker et al. 2004).

More generally, OECD countries have more than tripled their R&D personnel since the 1980s. Strong increases occurred during the mid-1980s and after the mid-1990s, coinciding with an intensified public debate about the knowledge economy at that time (Stehr 1994; OECD 1996; WB 2003; Välimaa and Hoffman 2008). The growth of R&D personnel in OECD countries remains linear adding around 4% of knowledge-intensive jobs per year to labor markets and accounting for almost 1% of all jobs. This trend began later for non-OECD countries and since the late 1990s these countries have doubled the number of professional knowledge workers as growth rates for the last decade have converged between both OECD and non-OECD countries reporting a 2.6% annual growth rate. Such a delay supports arguments that the knowledge economy was a phenomenon of wealthy nations before it reached other societies, notably the emerging economies in East Asia and Latin America (Zapp 2017).

The knowledge-based transformation of labor markets is also strongly driven by the private for-profit sector where growth is much stronger than in higher education and as predicted in early accounts (Bell 1973; Drucker 1969). At the same time, the role of education and strong state support appears to be crucial in understanding the large-scale process of economic transformation at work.

Having a robust public higher education system emerges as the strongest and most consistent predictor of large R&D personnel growth. State-led postsecondary systems are consistently more likely to propel R&D capacity including in the private R&D sector. Within this group of strong state-backed systems, we find such diverse cases as Singapore, South Korea and Denmark which all prove that strong state oversight does not contradict the dynamic of R&D expansion (Cantwell and Mathies 2012; Etzkowitz and Leydesdorff 2000; Mok 2010). This finding is also in line with previous research which sees the state as an active agent in "interventionist" research governance (Zapp, Helgetun and Powell 2018; Elzinga 2012; Cozzens and Woodhouse 1995). The extent to which state involvement matters might come as a surprise and will require further scrutiny in future research. Schofer and Meyer (2005), for example, use the degree of political centralization as an alternative measure of state control, finding negative effects on higher education expansion. However, their variable is not time-varying (it represents the situation in 1970) and, more importantly, in many countries a decentralized structure does not mean low state involvement in educational matters (e.g. Canada, Belgium, Germany). It is likely that the variable used in this study, i.e. large share of public higher education, reflects multiple overlapping institutional characteristics. Instead of assuming strong states use education to control society (as in Communist regimes), we could argue that they use education to steer the economy. Inasmuch as countries can constrain access, they can also flood higher education with the same political will to leapfrog their economies. Interestingly, it is rarely acknowledged in the extensive literature on the booming private sector that, in parallel to the (undoubtedly impressive) growth in private higher education, the number of public institutions has also been growing at a similarly high rate and continues to accommodate the majority of students worldwide (Buckner and Zapp 2021).

Further, higher tertiary enrolment, although weaker in its effect size, is associated with R&D growth across all models supporting the large literature on the transformative role of an increasingly educated society (e.g. Baker 2009). The effect of tertiary enrolment is higher outside the OECD where growth rates have been catching up with OECD countries and their earlier expansion (Schofer & Meyer 2005; UIS 2019). While previous research has established a relationship between higher skills (via higher education) and occupation status as well as earnings, this finding contributes to understand the more fundamental process at work as tertiary education might indeed drive the rationalization and "academization" of job content in general (Baker 2014; Goldin and Katz 2009; Wyatt and Hecker 2006; Zhou 2005). As university graduates carry their analytical skills to the job market, they increasingly import and apply cognitive templates of abstract and universalist thinking and transform what was once a routine task into an opportunity for knowledge creation (Schofer, Ramirez and Meyer 2020).

At the same time, specific academic training like doctoral schools, matter only in the context of higher education. This finding makes sense, especially given that Frascati-data is collected regardless of educational degrees. The fact that the importance of academic professionalization is only modestly correlated with higher education R&D expansion and even negatively correlated with R&D expansion in the corporate sector might, in addition, point to a bottle-necked pipeline where large numbers of graduates queue up for a limited number of PhD-adequate positions (see Wotipka et al. 2018 for a similar argument). In this perspective, it appears that the knowledge economy is largely decoupled from traditional academic training at the doctoral level, an argument that might help update earlier accounts of professionalization processes (Abbott 1988; Brint 1994). Alternately, the reason for the negative relationship between R&D expansion and firms might be that firms are hesitant (and sometimes even resistant) to utilize employees' full skills potential and, instead, in an effort to increase productivity, prefer to routinize job tasks – increasingly supported by artificial intelligence. As recent studies found, such underutilization of skills actually leads to a decrease in productivity and decline in skills (see, for example, Lane and Murray 2015; Quintini 2011).[7] Without delving into the notoriously difficult discussion on how to measure skills mismatch and over-qualification, future research might benefit from this analysis to further investigate companies' (in)capacity to adequately utilize academic skills.

The state also enters as a funder of R&D. High investments are consistent predictors for R&D expansion except for the academic sector where they become negative, which is probably explained by the separation between R&D and higher education funding in most countries. Large multi-year and multi-theme funding programs, which usually reach out to various sectors (including the corporate sector), are examples of how economic transformations can be propelled (Zapp, Marques and Powell 2018). The finding that these investments matter more outside the OECD might be explained by the higher growth rates in these countries (OECD 2019). Additionally, specific state-led research programs like excellence initiatives can now be found everywhere in the world (see Ramirez et al. 2016).

Moreover, it seems that the knowledge economy grows concomitantly with development, yet the causal relationship is difficult to ascertain. Economic growth is a multidimensional phenomenon just like the expansion of R&D under study here. Whereas the prevailing argument holds that knowledge is the engine of development, it is unclear which sector is concerned with such development. The large service sector as included in additional models (Appendix B, electronic supplementary material) shows no significant effect and in more traditional arguments, knowledge is a response to growing social complexity and not its primary cause.

Perhaps surprisingly, democracy shows no significance. As Figure 2 indicates, R&D growth is a global phenomenon including all kinds of polities and some countries have high growth rates yet low democracy scores (e.g. Singapore, China). This discrepancy illustrates that the occupational and economic transformation under study here – like others before – can again take place in the absence of a decidedly liberal political order. While a democratic system seems to favor higher education expansion (Ramirez 2002; Schofer, Lerch and Meyer 2018), for the business sector, the analysis even finds a negative association (albeit not significant).

At the same time, INGO membership – as a barometer of openness to world society – matters in the more recent post-1990 period and across sectors supporting the argument that R&D expansion is closely tethered to particular forms of globalization. Science, research and, in general, any form of modern rational knowledge flourishes most in exchange with international collaborators (Adams 2013; Finnemore 1993; Heilbron 2014). Science associations are an indication of how well a country is connected to the global knowledge discourse and even though R&D does not seem to require a liberal polity, it seems to thrive most where expertise can flow freely (Schofer 1997). In this, the transformation of national economies into knowledge economies might represent a blueprint of national development, promoted by

[7] I would like to thank an anonymous reviewer for raising this point.

all kinds of international organizations and eagerly absorbed in national development plans by political decision-makers around the world, often despite the absence of evidence for how viable such a model actually is – as has been shown for many other policies and sectors before (Drori et al. 2003; Zapp and Dahmen 2017). Interestingly, across OECD and non-OECD countries effects of INGOs reverse with non-OECD countries showing strong association. This might suggest that such blueprints of the knowledge economy are imported from frontrunners via these international organizations (e.g. the WB and OECD) as transmitters of global models before they are taken up and translated into national economic policy.

It is important to note, however, that all these concomitant factors ultimately depend on the interplay of an educated citizenry and the state as an open, i.e. embedded in world society, and strong, i.e. in terms of funding and higher education regulation, supporter, which together, provide fertile conditions for knowledge-creating jobs to emerge. Awkwardly, the results imply that future studies need to consider the role of the state in both its liberal and illiberal variants. This might come as a surprise as, historically, education and science have flourished most where individual liberty was strongest (Ben-David 1971; Merton 1968) and they remain targets of illiberal ideology worldwide up until today (Schofer, Lerch and Meyer 2018). Reminiscent of the varieties of capitalism (Hall and Soskice 2001) and the varieties of mass education expansion (Boli et al. 1985), this study suggests that there might well be varieties of the national knowledge economy, however, with a democratic polity being a non-essential condition for success.

Conclusion and Outlook

Analyses presented in this article suggest that the rise of the global knowledge economy is, since the mid-1980s up until today, indeed a tangible phenomenon reflected in the large-scale expansion of R&D-related jobs worldwide, yet particularly in high-income countries with strong public higher education sectors, high levels of enrolment and funding, and deep linkages to world society. While the knowledge economy is a heterogeneous transformation, it is ultimately characterized by a growing importance of original, creative, and non-routine tasks which are increasingly valued across forms of government, sectors, industries and institutional settings.

Future studies might benefit from including knowledge-intensive personnel data presented in this paper as both dependent and independent variables. For the latter, the growing body of research interested in scientific output and collaboration, and also economic growth in general (Powell et al. 2017; Schofer, Ramirez and Meyer 2020), could increase precision by controlling for R&D personnel.

Additional predictors could help improve the explanatory models presented here, in particular concerning shrinking capacity. Many former communist countries have seen major drops in R&D personnel, probably due to the emigration of a highly skilled labor force once borders opened up after 1990. As specific models cannot prove the relevance of a communist transition, the underlying mechanism more likely reflects emigration as a more general phenomenon. Although difficult to obtain, longitudinal data on international mobility of high-skilled workers could help in assessing whether and how strong outbound mobility impacts innovation systems and would provide a sounder basis for debates on brain gain and brain drain, both across countries and sectors.

Finally, while the knowledge economy is usually celebrated as a cleaner, greener and healthier economic era, with opportunities for all, its aggregate effects on labor markets and particular job segments remain subject to debate (e.g. Frey and Osborne 2013). The knowledge economy may not imply a simple zero-sum game in which knowledge creators win and mere users and reproducers lose, yet it will be an important task for future research to identify the consequences of the "cognitive edge" for labor market access and income equality but also geopolitical positioning and the liberal order on a global scale. The ambiguous role of the state in steering these processes and reaping its benefits – just as in creating them – would then require particular attention.

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