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How it all began: The long term evolution of scientific and technological performance and the diversity of National Innovation Systems*

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Abstract

The aim of this article is twofold. First, we are interested in analysing the long-term dynamics of science and technology at country level to investigate the roots of countries innovative success and to ascertain the historical origins of the so-called "European Paradox". Secondly, we carry out a taxonomic exercise to empirically verify the existence of different type of NSIs. Preliminary results show that no European paradox exists, at least in science. Europe still lags behind the United States in terms of top-notch research. Furthermore, the historical examination highlights that US scientific leadership starts back in time, definitely overtaking Germany and UK right after WWII. Both publication and patent data show very asymmetric performances among European countries, where differences have ancient roots. The remarkable technological catch-up of Japan and, to a lesser extent, South Korea are highlighted by the historical perspective adopted. Then, the taxonomic exercise shows the existence of three different groups of countries (i.e. the "Leading Elite" - the advanced countries - the "Fragile Catching-up" - the Eastern and Southern Europe countries - and the "Missed Opportunities" - the Latin American countries) with rather significant differences in their level of scientific and technological production, level of education, and propensity towards product or process innovations.

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1 Introduction

The *National Systems of Innovation* (NSI) approach has emerged over the last twenty years within the broad field of innovation studies. In a nutshell, the NSI approach works out the implications for the scientific and technological performance of countires of a characterization of the innovative processes as inherently "systemic" and "complex" activities . In fact, NSI presupposes that innovation and technical change result from a complex pattern of interactions among a wide variety of actors, such as firms, universities and government research institutes. The popularity of the concept of NSI suggests that it has provided policymakers with a seemingly effective analytical tool-kit and fostered the debate on policies to promote innovation and sustainable economic growth (Fromhold-Eisebith, 2007; OECD, 1997). However, a theoretical convergence on a rigorous definition of NSI is still lacking. The seminal contributions developed by Freeman (1987), Lundvall (1992) and Nelson (1993) provide fundamental insights on the main drivers of innovations at the national level, using rather different conceptualisations of the NSI framework. While Freeman (1987) highlighted the importance of historical and institutional factors in the Japanese catching up, Lundvall (1992) stressed the relevance of learning interaction among different agents such as firms, universities, and users. On a rather different ground, and taking a somewhat narrower perspective, Nelson (1993) was mainly concerned about the formal R&D sub-system and therefore he focused his attention to scientific and technological performances of nations. All these three authors have pointed to the relevance of science, technologies and institutional dimensions; however, they are noteworthy differences on the relative predominance of one factor with respect to the others.

An interesting result of the empirical literature on NSI is the wide heterogeneity in "successful" NSI configurations Nelson (1993).Interestingly enough, the interplay between scientific and technological developments is also at the core of the so-called "European Paradox" stream of policiy literature. This perspective is essentially essentially concerned with the factors accounting for the widening gap between Europe and the US in terms of innovation and economic growth. The term paradox emerges from the observation that, despite Europe plays a leading role in scientific developments, it lacks the entrepreneurial capacity of translate them to technologies and innovations. Whereas, on the other hand, the US seem more able to capitalize on their scientific developments with a better capacity to transfer scientific discoveries in the market (European Commission, 1995). However, the existence of such paradox has been debunked by several authors (King, 2004; Dosi et al., 2006; Leydesdorff and Wagner, 2009) who claim that the notion of paradox is not corroborated by the empirical evidence and the claim of a European leadership in the scientific domain is, in fact, not warranted.

Building on these considerations, the aim of this article is twofold. First, we are interested in analysing the long term dynamics of science and technology at country level in order to understand the roots of the cross countries differences in the "minimal common block" of the NSIs notion (ie, scientific and technological activities).

We use a novel dataset on indicators of scientific activities - such as articles published on peer-reviewed academic journals, number of Nobel prizes, number of highly cited researchers - to provide a broad historical quantitative reconstruction of the scientific history of European countries and of some selected Latin American countries in comparison with US and Japan. This analysis is combined with a through assessment of technological performances - always in a historical perspective - through patents data. This integrated analysis of scientific performance indicators and technological measures allows us to probe further into the historical roots of the "European Paradox" (if any).

Secondly, departing from the qualitative literature (Nelson, 1993) on the existence of a variety of successful NSI we propose a taxonomic exercise and an empirical test. We use factor and cluster analysis on an ad-hoc country level database covering the 2000-2011 time span in order to empirically test the existence of different type of NSIs. Building upon existing literature on measuring capabilities at country level (Fagerberg and Srholec, 2008, 2015a,b) we focus on elements that most likely affect country level innovative capabilities (e.g. education, trademarks, patents, government procurement, etc.). Furthermore, a point of novelty of our exercise is the inclusion in the analysis of country-level data from innovation surveys which provide us with a detailed characterization of the nature of innovative processes in different countries (Mairesse and Mohnen, 2010).

Preliminary results show that no European paradox exists. In fact, Europe still lags behind the United States in terms of top-notch research. Of course, due to possible language bias might underestimate the science base of non-English speaking countries such as Germany and Japan. However, evidence of scientific quality not based on publications (e.g. Nobel prize laureate) further confirms the enduring scientific leadership of US. Our historical perspective shows clearly that the US leadership starts well back in the past and that all European policies aiming at improving its scientific performance have not been fully successful. At the same time, Latin American countries have continued to play a marginal role in scientific production, throughout the period considered; while China is rapidly putting aside its role of scientific follower, gradually approaching the scientific frontier that for more than a century has been prerogative of the triad EU-USA-Japan. Patent data testify the successful story of Japan and, to a lesser extent, South Korea. Regarding the taxonomic exercise, the factor analysis extracts three factors, each one consistent with a specific conceptualisation of the NSI. Accordingly, we have labelled the factors "Freeman", "Lundvall", and "Nelson", respectively. Using cluster analysis on these three factors we were able to identify three groups of countries displaying rather different levels and trajectories of capabilities accumulation. The three clusters are the "Leading Elite" (i.e. the advanced countries), the "Fragile Catching-up" (i. e. the Eastern and Southern Europe countries), and finally the "Missed Opportunities" (i.e. the Latin American countries). These groups shows significant differences in their level of scientific and technological production, level of education, and propensity towards product or process innovations.

The paper is structured as follows. We presents a review of the literature on NSI in Section 2 and an introduction to the debate on the "European Paradox" in Section 2.2. Section 3 presents novel empirical evidence on long-term trends of science and technology dynamics. Section 4 and Section 5 describe the data and methodology, and the results respectively of the taxonomic exercise. Conclusions will follow.

2 Literature review

Over the last twenty years or so, the notion of National Systems of Innovation has shown to have a wide appeal to scholars and policy-makers. Yet, at the same time, the concept has remained somewhat elusive and difficult to articulate in a clear-cut way, so that even distilling an agreed definition from the literature is far from straightforward.

The NSI notion was perhaps born during the late 1980s, gradually emerging inside the evolutionary and institutional traditions of innovation studies. As reported by Lundvall (2007), the first explicit use of the term "national innovation system" is due to Chris Freeman Freeman (1987) first in an OECD paper and, subsequently, in his seminal analysis of the Japanese economic miracle after WWII. However, the term became popular and widely used after the very close publication of Lundvall (1992) and Nelson (1993) edited books that explicitly mentioned the term in their title. The latter can be seen as marking the definitive consolidation of the relatively recent tradition of evolutionary innovation studies, whose origin may be traced to the foundation of the Sussex's Science Policy Research Unit (SPRU) by Chris Freeman himself. In a recent paper, Fagerberg et al. (2012) has provided, using bibliometric data, an effective characterization of the historical evolution of innovation studies as a field of research. By means of a cluster analysis, Fagerberg and his associates are able to identify three main research branches from the economics of innovation literature: "organizing innovation", "economics of R&D" and "innovation systems". The central works of the latter domain are precisely the aforementioned books of Freeman, Lundvall and Nelson.

Without lingering on its historical roots, dating back to Friedrich List (Freeman, 1995), we shall examine the different articulations of the NSI notion. In this respect, a very useful contribution is the Soete et al. (2010) "galaxical guide". Soete and co-authors argue that, even if all the NSI literature is in broad agreement in acknowledging the key-role of institutions, the interactions among agents and the role of the state, the NSI concept can actually be declined in three different flavours, each of them emerging respectively from the contribution of Freeman, Nelson and Lundvall.

The distinctions between the three flavours of the NSI notions may be summarized into a proper taxonomy, which we try to sketch out in Table 2. Indeed, the affinities of the three versions of NSI are much more important than their divergences (see Part V in Dosi et al., 1988); nevertheless, pointing out the different analytical perspectives can provide us with some valuable insights.

Freeman adopted an institutionalist approach that turned out to be very effective in describing the case of Japan. His approach takes in due consideration the role played by history and institutional embeddedness in affecting the innovative performance of agents; in a sense, it may be defined as a 'broad' conception of NSI (Table 1). The focal point of interest concerns the factors affecting successes and failures of industrial and innovation policies. The Japanese experience is a remarkable example of how relatively enlightened policymakers can put in place effective industrial policies without resulting in ineffective excesses of dirigisme.

Without ruling out the important role of policies and institutions, Lundvall proposed an even broader - though less historically articulated - systemic perspective. According to Lundvall, knowledge should not be understood in static terms (in this respect the notion of a knowledge production function is highly misleading). Knowledge production is inherently a complex learning process in which a wide variety of different types of agents (firms, universities, inventors, banks, users, etc.) are involved. A successful innovation systems, in this perspective, is a system that is able to foster these type of learning by interactions.

Finally, it should be noticed that, even if Nelson never neglected the importance of institutions and of the wider system

Table 1: Different aspects of NSI and their interactions

	NARROW	BROAD
FORMAL	Science and technology organizations, institutions and formal networks *(firms, universities, research centres, Government policies)*	Organizations supporting innovation in general, institutions and formal networks *(education and financial system, unions)*
INFORMAL	Science and Technology informal institutions and informal networks *(relationships customer/supplier, cooperation, business orientation)*	Informal institutions influencing innovation and informal networks between actors and institutions *(cultural and historical values)*

Source: from Lundvall et al. (2009) p. 11. The examples in italics are ours.

in which industrial and academic research is embedded, he was primarily concerned with the empirical measurement of scientific and technological performance. Accordingly, the focal point of the NSI in the Nelson tradition is the formal R&D sub-system; the result is a rather 'narrow' narrative (Table 1). His approach is pretty much the same as the "Triple Helix" put forth by Etzkowitz and Leydesdorff (2000), in which they explicitly limit their analysis to a DNA-like model made of firms, government and universities (with the latter being the main actors). Nelson clearly suffered from a "US bias", having been witness of the role played by big-corporations labs and government funded-universities in establishing the stars and stripes scientific leadership (for an historical account, see Nelson and Wright, 1992). However, the challenge of finding indicators and measures of NSI able to capture the broader features implied by its definition remains open, as we shall see in the empirical analysis.

Besides the differences in the scope of the NSI definition (and therefore of the actors to be included in the picture) it is worth briefly going through some of the challenges the NSI theorization is facing. The first one concerns the effectiveness of its actual implementation by policymakers. As Lundvall himself recognised in a paper written in 2007, the NSI was quickly adopted in the policy debate on innovation and industrial policies; nevertheless, policymakers often pay lip-service to the term while disregarding it in practice. Other challenges are on the theoretical front. Edquist (2004) strongly criticized the lack of agreement on a single working definition of national innovation system, thus labelling it as a concept rather than a proper theory. A further theme is expanding the scope of the system perspective in order to use it as a developmental tool for poor countries (Lundvall, 2007).

To sum up, the strand of research on national systems has provided so far several valuable insights and results. However, it now faces several challenges both theoretical and empirical, paving the road for research aiming to reshape and modernize the NSI concept.

2.1 Measuring innovation capabilities

The strength of the NSI approach lies in its capacity to capture the qualitative and interactive aspects of innovation. However, the genesis of the NSI research agenda was at least twofold. At the outset, it levelled a powerful criticism to the neoclassic paradigm and its "reductionist" analysis of innovation dynamics. But in addition to its theoretical contribution, the NSI tool highlighted the institutional instruments needed to economic growth or catch up, while, at the same time, providing policymakers with grounded comparative evidence about the policies to be put in place. For example, it provided an effective comparative characterization Dosi et al. (1994) of the performance of the national innovation systems of Latin America and East Asia, resulting in some remarkable "strong" policy prescriptions. This kind of analysis has the advantage of being adherent to the academic literature, since it is able to evaluate also institutional factors. However, it is a method difficult to operationalize, thus not allowing for comparison among bigger numbers and varieties of countries.

The problem of studying heterogeneous countries is dealt with in the Nelson's book of 1993 by assigning to each chapter the in-depth study of a single national system. Some of these chapters represent very influential and relevant contributions, adding to the exploitation of a huge quantity of data on education and technology performance an interesting theoretical characterization. Although the Nelson's edited book has become a cornerstone of the discipline, its

Table 2: A tentative taxonomy of National systems of innovation theorizations

Author	Freeman (1987)	Lundvall (1992)	Nelson (1993)
Country of inspiration	Japan	Denmark	United States
Aspects emphasized	Institutions interplay, deliberate state policies	Learning, user-producers interactions	Universities and firms' formal R&D effort
Main features	• State policy (MITI) • Technology forecasting • Corporate R&D • Human capital and technical education • Conglomerate industrial structure and co-operation • Institutions	• Learning as the most important feature of the system • Incremental and cumulative nature of innovation • Interactions (mainly of the user-producers form) • Institutions	• R&D expenditure (just formal) • Input (GERD) vs Output (patents, publications) of the system • Science and technology interplay • Institutions that support formal R&D
Definition	Broad	Broad	Narrow

Source: our elaboration from Soete et al. (2010), Freeman (1987), Lundvall (1992) and Nelson (1993)

approach is not ideal for practical purposes. The abundance of details in each country chapter comes at the expenses of comparability, the whole exercise adding up to a collection of static and stand-alone pictures. This is where the Patel and Pavitt (1994) appeal for quantitative analysis clarifying the properties of national systems comes in. They argue the case for improving the empirical basis for understanding and evaluating national performances, in the form of comparative and quantitative indicators. Furman et al. (2002) and Furman and Hayes (2004) built on the NSI literature in order to develop their 'national innovative capacity' concept, defined as the ability of a country to produce and profit from a long-term flow of innovative technology. They postulate that this capacity rests on three factors, namely the strength of a nation's innovation infrastructure, the propensity to innovate in industrial-clusters, and the linkages between these two sub-systems. While stating their debt of gratitude to the Nelson's definition of national innovation system (indeed the narrower one), the above mentioned Authors reduce the vast theoretical NSI contribution to a mere emphasis on the "political implications of geography" (national policies and institutions). Unfortunately, their perspective seems to trivialize a concept much wider, without adding much to the analysis. By means of this strong simplification, they are therefore able to estimate an empirical version of their model. In order to do that they use as dependent variable for technological performance the number of USPTO-granted patents, which is supposed to be indicative (output) proxy of national innovative capacity. We will not analyse here the pros and cons of such a choice, which are widely known (see Archibugi, 1992, for a review). The only point worth noting is the very narrow approach followed, which traded off the majority of the true insights brought by innovation scholars in exchange of a quantitative measure.

Since a single measure of innovative performance is not informative enough, the alternative is recurring to a composite index measure. The problem of an arbitrary choice is not reduced by weighting and summing up a number of different proxies. Archibugi and Coco (2005) describe and compare several composite indexes of technological performance. We definitely agree with their claim that, despite limitations, synthetic measures of differences across countries may be useful and even desired by policymakers. The important assumption here is that the various technological capabilities[1] are complementary and not substitutes, i.e. it is possible to sum them up. This is the approach currently pursued by various reports produced by international organizations. Nevertheless, the construction of indicators of the kind are usually void of theory and only based on very simple empirical methods, with limitation as straightforward as their construction is: data availability and, again, arbitrary choice of indicators. For the former problem there is not much that a researcher can do; for the latter, an alternative technique may well work.

[1] Archibugi and Coco (2005) summarize their heterogeneous nature in three broad categories: Embodied/Disembodied, Codified/Tacit, and Generation/Diffusion.

Fagerberg and Srholec (2008, 2015a,b) try a completely different approach. Instead of choosing a couple of variables, they assemble a set of indicators considered relevant for the description of the phenomenon and construct a composite variable. In this respect, the underlying assumption is that indicators reflecting the same dimension of reality should be expected to be strongly correlated so that they can use a variable reduction technique in order to summarize a vast amount of information in a smaller subset of variables. They perform a factor analysis, i.e. a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors. By means of this technique, in the 2008 paper they are able to characterize the various countries along four dimensions, namely "innovation system", "governance", "openness" and "political system". The advantages of such analysis are several, allowing for a multi-dimensional description of a national system (with a 360-degree measure of its capabilities) and reducing the space for arbitrary choices.

2.2 The European Paradox

The "European Paradox" can be described as the conjecture arguing that, despite playing a leading role in terms of scientific excellence, Europe lacks the capacity of the United States to transform its excellent scientific output into industrial innovation and therefore economic growth. Within this general statement, the paradox assumes different shades, since it includes a wide range of peculiar deficiencies hampering the innovative activity (European Commission, 1995). The rhetoric of the paradox has been introduced by the European Commission during the mid 1990s in order to stress the idea that Europe was not effectively exploiting the results of its scientific research activity.

After the Green Paper was published, the European Paradox became a popular topic that triggered several strands of academic literature. Several scholars have explored the reasons and consequences of the paradox conjecture.

Using a bibliometric approach on the ICT industry (a field in which Europe is relatively weak) Tijssen and Van Wijk (1999) find slight evidence of the paradox existence: EU basic research seems of high scientific quality, while the European ICT industry is less involved in research efforts. Indeed, the study also finds that Europe is extensively using its local knowledge, casting some doubts on the existence of a exploitation gap in the European science-technology interface.

An other strand of research examined the effectiveness of national R&D expenditures among European countries, showing huge variance among European Countries (May, 1998). In turn, this translated in policy suggestions, such as the creation of a common European Research Council in order to help Member States to import best-practice and improve their performances in scientific research May (2004).

The "European Paradox" has the merit of having brought the attention on the quality of the scientific output and how best evaluate it.[2] For instance, May (1997) suggests that bibliometric studies may fall short on correctly evaluating non-native English scientists, since language can partially explain the gap of publications on international top-journals. However, also when adjusting for the linguistic bias, Europe lags behind both in terms of scientific inputs and output is found, in sharp contrast with the paradox hypothesis. King (2004) evaluated the relative strength of Europe in several disciplines. He found a mixed picture, with US superiority in life and medical sciences, while Europe performed slightly better in engineering and physical sciences. The main point he successfully emphasised is the marked variance among EU players in the field of scientific research and the lack of any claimed superiority of European science base. On the same line, Leydesdorff and Wagner (2009) used the Science Citation Index to investigate how US and EU-15 were really performing in science. They focus on the top 1% publications in terms of citations, finding that despite the European numeric lead in total publications, the two players are still far apart in the top segment of the most highly cited papers. This result is further confirmed by Albarrán et al. (2010), who worked on data drawn by the ISI-Thompson Scientific database. They confirmed the results of Dosi et al. (2006): among the most influential articles, in 21 out of the 22 scientific fields considered the dominance of US over EU is overwhelming. Finally, further exploitation of similar data has been done by Herranz and Ruiz-Castillo (2013), showing again that the United States do outperform Europe in their scientific performance.

Within this stream of literature the analysis by Dosi et al. (2006) bears important consequences. In fact, it undermines the first and central claim of the paradox conjecture: namely, the claimed European superiority in its science base and scientific production. United States are shown to be ahead of the Old Continent in qualitative terms, displaying more top publications and the majority of prominent researchers. They clearly demonstrate that the European Paradox no longer existed (if it ever did). Talking of European scientific leadership and of deficiencies in its industrial conversion is

[2]Note that The Green Paper on Innovation took the total number of paper published as a proxy of the 'quality' of European science, which is not only misleading but also substantially wrong.

a non-sense, simply because both science base and industry are at least fragile, if not weak. This will be our starting point: in order to understand why Europe is lagging behind the United States, we are going to explore scientific and technological dynamics on an historical perspective.

3 Descriptive evidence on science and technology in Europe

The aim of this section is twofold. First we would like to contribute to the empirical evidence on the relative strength of the European science base as compared to United States and some Latin American countries. In particular, we are interested in moving ahead from simple publication and citations data integrating them with other novel data. Secondly, we are interested in introducing an historical perspective analysing long term trend in science and technology indicators.[3]

As first noted by Dosi et al. (2006), the original evidence on which the notion of the paradox was formulated is the total number of European scientific papers, with Europe overtaking the United States. This achievement was accomplished, notwithstanding the language bias suffered from many EU member States whose native language is not English.[4] However, this conclusion is at least simplistic. Dosi et al. (2006) found a completely different story by simply adjusting for the sheer size of the compared countries. In Table 3 we update and enlarge this preliminary exercise, giving a picture of the situation in 2014. The first column shows that despite the growing number of scientific articles published, in per capita terms Europe still lags behind the United States. This in turn is due to both a greater productivity of American researchers and the bigger share of workers involved in research activities (columns 2 and 3). Japan has a very few publication per capita, despite a very high number of researchers. However, the number of publication per researchers is the lowest, hinting to a great influence of the language factor. Latin America shows the worst overall performance. This is due to the very small number of researchers, since on average they do not publish much less than their European or American colleagues. China is added because of its growing importance in research, but still rather limited as compared to advanced countries.

The remaining parts of Table 3 are meant to further investigate the nature of the paradox, if ever present. In its original formulation, the total number of publication contained no correction or proxy for quality. Despite the scientific publications we consider have all gone through a peer-review process, it is quite straightforward assuming that they do not display the same quality or do not advance the corpus of science in the same proportion. We try to account for the quality of scientific activity in two different way. On the one hand, we consider those papers that are the most cited in their respective fields. On the other, we take the number of publications on the very prestigious journals Science and Nature: irrespective of the number of citations, the articles published on these journals have to meet the highest standards and underwent a particularly rigorous review process. The main finding is that in both cases the United States outperforms Europe, the difference being here much bigger than when considering the total number of publications. Finally, we repeat the same exercise with the Highly Cited Researchers list compiled by Thomson Reuters (see Appendix B). The results show even more the stars and stripes dominion. This preliminary overview brings broad support to the hypothesis argued by Dosi and his co-authors, namely that the paradox never existed in light of the fact that Europe still lags behind in terms of top science (Dosi et al., 2006). Despite twenty years of debate and policies aiming at tackling the European paradox, nothing is really improved or changed.

3.1 Long term trends in scientific performance

In this section we will add an historical dimension to the analysis of the scientific dynamics of Europe and Latin America. In order to do so, we exploited the information present in the databank of Scopus and ISI-Thomson Reuters (Core Collection). For information about methodology and coverage of the analysis, see Appendix A and B.

We start by analysing the pattern of total published scientific papers, as a proxy of scientific advance and novelty generation. Measuring the "Scientific Wealth of Nations" (May, 1997; King, 2004) has become increasingly important for resource allocations and policy design, the European Paradox being just an example of this. We have considered articles published only on peer-reviewed journals, because of the key-role of peer-review in science. In principle, the

[3]For an explanation of possible caveats of using popular publication databases for an historical analysis see Appendix A.

[4]As the paradox advocates emphasized, even considering only English articles, Europe outnumbered US. Furthermore, the European figures are deemed to be underrated due to all the articles not counted because published in languages other than English, Europe science base must be much better than the US one.

Table 3: Publications and Highly Cited Researchers weighted by population and total researchers.

	Publications/Population	=	Publications/Researchers	x	Researchers/Population
EU15	0.93		0.27		3.40
EU28	1.06		0.28		3.76
USA	1.25		0.32		3.97
Japan	0.60		0.12		5.20
Latin America	0.13		0.25		0.54
China	0.18		0.17		1.09

	HCPapers/Population	=	HCPapers/Researchers	x	Researchers/Population
EU15	9.67		2.85		3.40
EU28	11.88		3.16		3.76
USA	18.36		4.63		3.97
Japan	4.48		0.86		5.20
Latin America	1.14		2.12		0.54
China	1.68		1.54		1.09

	Articles S&N/Population	=	Articles S&N/Researchers	x	Researchers/Population
EU15	1.52		0.45		3.40
EU28	1.93		0.51		3.76
USA	3.64		0.92		3.97
Japan	1.12		0.21		5.20
Latin America	0.17		0.32		0.54
China	0.10		0.09		1.09

	HCResearchers/Population	=	HCResearchers/Researchers	x	Researchers/Population
EU15	1.67		0.49		3.40
EU28	2.04		0.54		3.76
USA	5.13		1.29		3.97
Japan	0.76		0.15		5.20
Latin America	0.01		0.03		0.54
China	0.10		0.09		1.09

Source: ISI-Web of Science (Core Collection), UNESCO UIS Database and World Bank WDI Databank. Data for 2014.

practice of peer review provides the necessary incentive compatibility between the basic norm of science disclosure and the reputation-based reward system grounded upon priority (Kassirer and Campion, 1994; Dasgupta and David, 1994). Despite not being perfect, Siler et al. (2015) recently showed that peer-review is capable of effectively discriminating between low- and high-quality articles, despite suffering of some conservatism that may prevent from rightly evaluate ground-breaking papers.

The graph presented in Figure 1 shows the shares of total English articles published from 1900 to 2014 by the world major scientific players. For every considered year, the share of a country is given by its number of articles on a peer reviewed journal as a percentage of the total number of article published by EU, USA, Japan and Latin America. The data were obtained recurring to total counting of the articles, a methodology that highlights international cooperation in science (see Appendix A for the details). Figure 1 shows that the European Union overtook the United States only very recently in the total amount of articles; however, the European catching-up started during the Golden Age and never stopped. Major European drops are present during both World Wars. Also Japan lost almost entirely his very tiny share during WWII, while the United States profited from both their losses. Finally, Latin America shows a very steady pattern, with his share constant until the 1990s, when a sustained growth started taking place.

The dynamics of some Emerging Countries are presented in Figure 2. Russia displayed a growing share during the

Cold War, when one of the "proxy battlefield" of the cold war was th challenge with the US for world scientific leadership. However, the decline and eventual collapse of the Soviet Union have interrupted the growth of his share and pushed it to marginal levels. China, completely absent until the 1980s, started an exponential growth that brought to an annual number of publications close to the combined figures of France, Germany and the United Kingdom.

At this point, a question arises spontaneously: what is the origin of the US leadership? Is the US leadership dating as back as 1900 as Figure 1 seems to show? The problem here is that when considering English articles as a proxy of science production, one is subject to a suspected language bias. So, USA and UK are in a position of advantage, since every scientific article is published in English. Non-English speaking countries actually have national journals published in their own language, but they do not concur in forming the publication output considered in these comparisons. This problem, particularly relevant for humanities, is supposed to fade away for hard sciences (Huang and Chang, 2008). Since English is the official language of international science, every researcher in the world would try to disclose his best results in English in order to claim priority on his findings (Dasgupta and David, 1994).

As a matter of fact, this assumption lies at the very core of every comparative exercise of the kind we are carrying out. However, limitations of this approach are evident. Countries like Japan, for example, have a propensity to publish in English very low relatively to their research capabilities (as made evident by simply considering the number of researchers, Table 3). Such a problem is likely to be much amplified when going back to the beginning of last century, when the modalities of scientific production were completely different. This becomes particularly clear when taking a closer glance to Europe, with the figure becoming very messy in the first half of the century due to the databases imperfect coverage (Figure 3). Science and its modes of production have completely changed during the last century, as witnessed by the exponential growth of output in the form of scientific articles (De Solla Price, 1965; Larsen and von Ins, 2010). Thus, these data are not capable of accounting for the German lead in science during the Second industrial revolution, or the big strides made by a country such as Italy after WWI. Several German journals of 1920s and 1930s were among the most prestigious in the world, a clue of the leading role of German science at the time. This is clearly underlined by an article published in Science in 1941:

> "Before the advent of the Nazis the German physics journals (Zeitschrift für Physik, Annalen der Physik, Physikalische Zeitschrift) had always served as the central organs of world science in this domain [...] In 1930 approximately 700 scientific papers were printed in its [the Zeitschrift für Physik's] seven volumes of which 280 were by foreign scientist" (American Association for the Advancement of Science, 1941, as reported in Waldinger, forthcoming).

A way to take a different look at this subject is turning to analyse the geographical distribution of Nobel prizes, which may work as a quite straightforward proxy of scientific excellence. The first to study the subject was Eugene

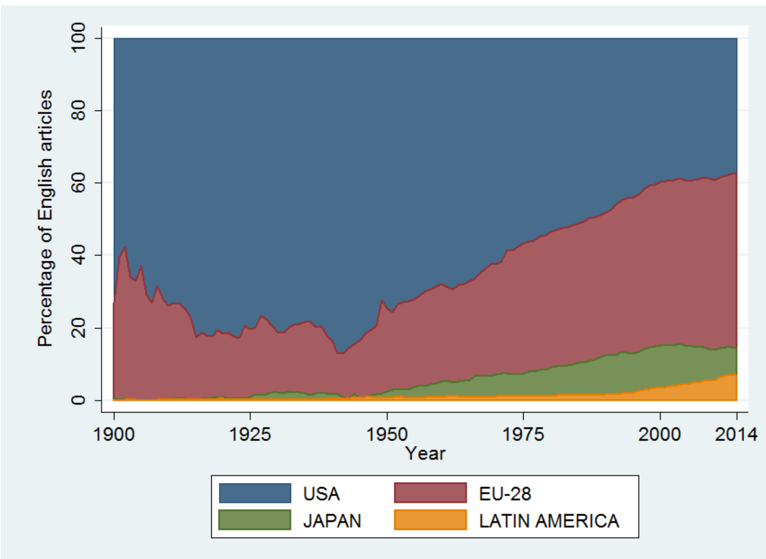


Figure 1: Shares of total English articles published on peer-reviewed journals, 1900-2014

Source: Scopus

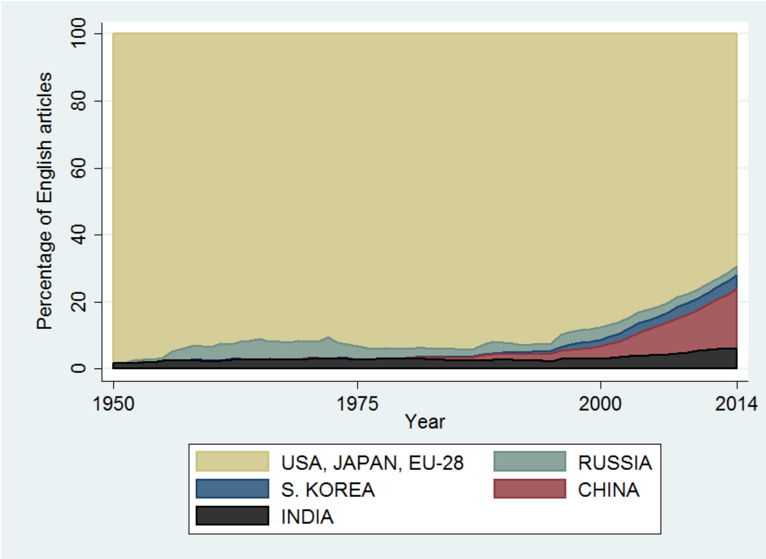


Figure 2: Shares of total English articles published on peer-reviewed journals by selected Emerging countries, 1950-2014

Source: Scopus

Garfield, who in several papers showed that Nobel recipients also matched several other proxies of quality (Garfield and Welljams-Dorof, 1992; for a recent assessment, Gingras and Wallace, 2010). Yearly attributed by the Royal Swedish Academy of Sciences and by the Karolinska Institutet, the prize was founded by Alfred Nobel in his last wills, in order to gratify "those who during the preceding year have conferred the greatest benefit to mankind". Due to the rigour of its assignation and its long-standing tradition, the Nobel prize soon became the most prestigious award in scientific and literary fields. Thus, the analysis of the distribution of Nobel laureates may offer us some historical perspective on the countries performances in top-notch science.

We collected the data of all the Nobel laureates in chemistry, physics and medicine in the period 1901-2015. We counted the total number of researchers awarded the prize, so if a Nobel in a given year appeared to be shared among

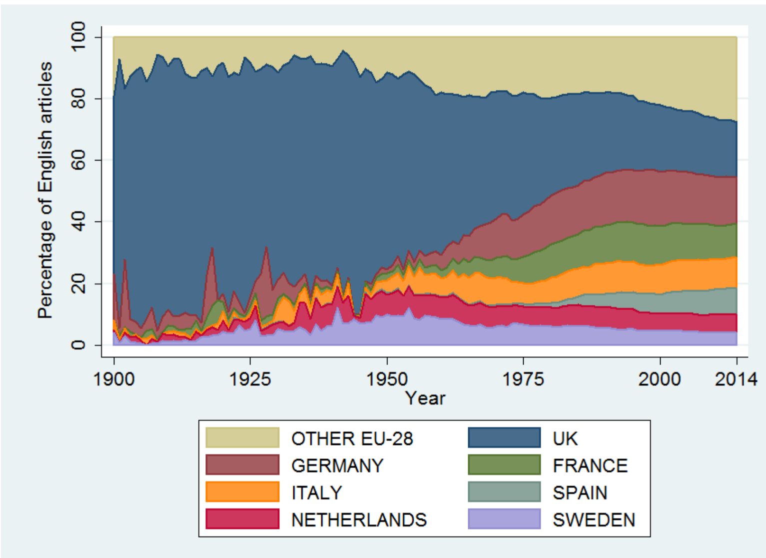
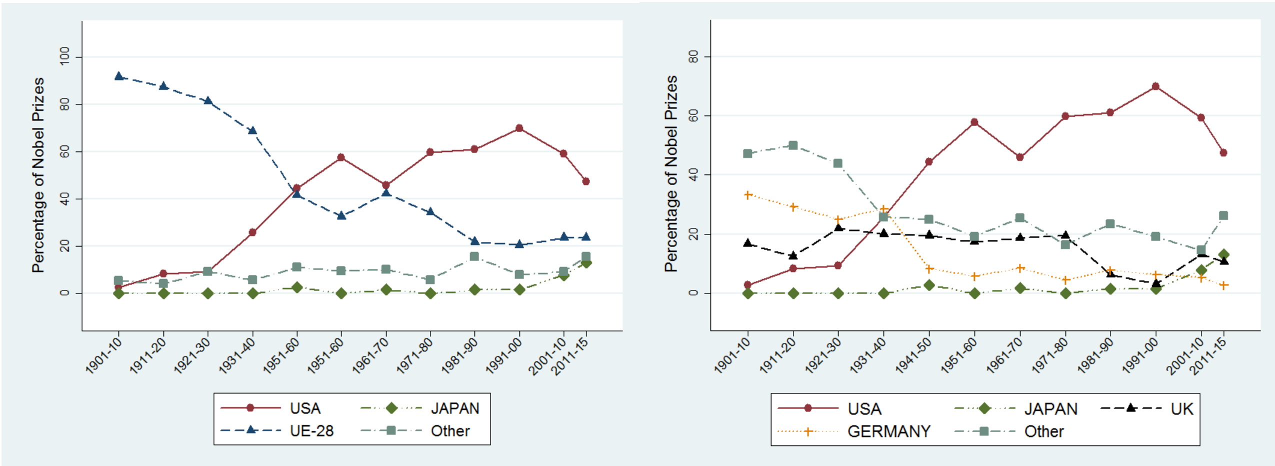


Figure 3: Shares of total English articles published on peer-reviewed journals by European countries, 1900-2014

Source: Scopus



(a) (b)

Figure 4: Share of Nobel prizes recipients by country's affiliation, 1901-2015

Note: The figures report the percentage of Nobel Prizes awarded in physics, chemistry and medicine to scientists affiliated with a university in the respective country for each decade from 1901 to 2015. Source: *http : //www.nobelprize.org/nobel_prizes/*.

three people, we counted each of them as a full recipient. The risk of double counting considering for each laureate with more affiliations only the first one. Finally, when attributing a Nobel winner to a particular country, we looked at his affiliation university or organization[5]. The result is a dataset of 583 Nobel laureates, distributed in 27 Countries (considered with present borders). Just three people won two different Nobels in those three scientific fields; they have been counted twice for their affiliation country.

Figure 4a shows a rather different picture of the timing of the emergence of US leadership (consistent with Nelson and Wright, 1992): after WWII, the United States took the lead at the expenses of the Europeans. But if we disaggregate more the EU share, we find that Germany received the largest share of Nobel prizes for the first 40 years of the twentieth century (Figure 4b). This proves that any consideration on English articles as a proxy for scientific performance before 1950 must be interpreted carefully, since the language bias is likely to reduce the landscape into a comparison between United States and United Kingdom.

Quite surprisingly, however, other countries whose science base is reknown for being particularly important show a very little number of recipients. Japan and Russia totalled in 115 years just 15 and 11 winners respectively, with Switzerland outperforming both. But if we take a closer look, we find that just 9 of the Swiss-affiliated winners were actually born in Switzerland (almost the 43% of the total). This accounts for the different countries appeal in attracting and retaining talents.

The data showed so far offer some interesting insights on how talented researchers are distributed in the world. However, the number of Nobel winner is very small and the assignation is made by a Committee whose decision, for as much as it can be deemed impartial, remains arbitrary. A better proxy of scientific excellence could be finding some impartial metrics for assessing the number of top researchers in a country. Thomson Reuters offers a complete list of Highly Cited Researchers (HCRs), based on the number of Highly Cited Papers they published (Appendix B for the details and definitions). The rigorous methodology adopted in compiling the list is a guarantee of scientific excellence and is a useful evaluative tool, but unfortunately the list is available only since 2014. However, it does exist a previous list of 2001 (and lastly updated September, 8th 2015), despite not being comparable with the new lists because of a deep change in methodology. This 2001 list identifies more than 7,000 researchers who were the most cited in one or more of the broad scientific fields defined by Thomson Reuters. Approximately 250 researchers in each field were selected based on total citations to their papers published during the period from 1981 to 1999.[6] A partial drawback of the analysis

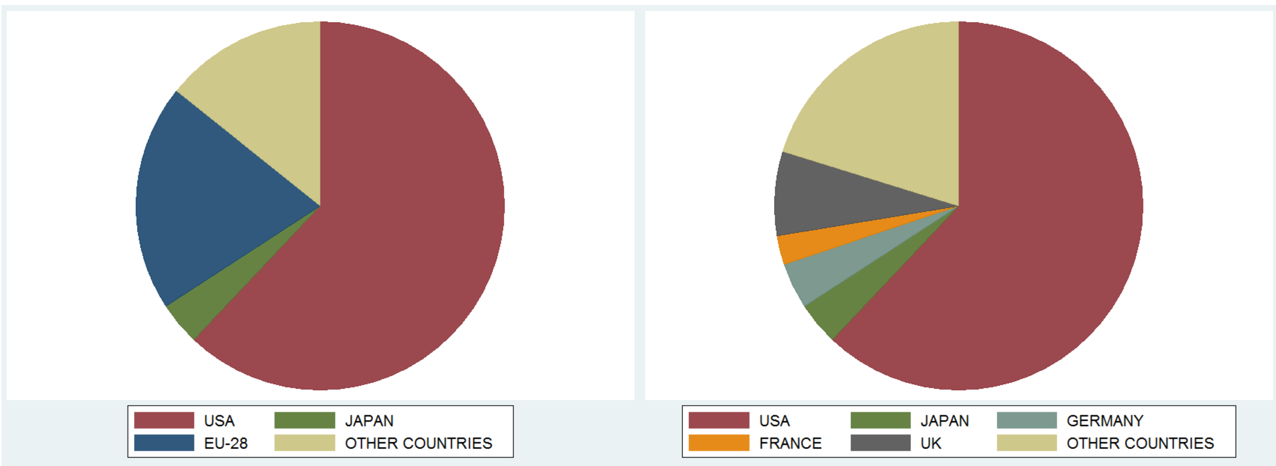
[5]For example, Guglielmo Marconi, Nobel laureate for physics in 1909, despite being Italian by birth carried out most of its work in the United Kingdom, where he was working when nominated for the prize. Thus, in our counting he is assigned to the score of the United Kingdom.

[6]Successive updates in 2004 (based on papers published from 1984 to 2003) and in the following years led to a number

is that it considers the researchers total number of citations, a criterion that gives results biased towards very prolific authors. Moreover, there was no correction for older papers, which had time to accumulate a larger number of citations. These problems account for the radical change in methodology starting from 2014; nonetheless, total citations remains a measure of gross influence that often correlates well with community perceptions of research leaders within a field (see Basu, 2006, for an application). The list can thus provide a synthetic overview of scientific excellence in the last twenty years of the twentieth century. Figure 5a and 5b plot the countries shares of HCRs in two different ways. Both graphics emphasize the predominant share of the United States (62%), partially explained by their leading role in the field of biotechnologies that emerged in those years (in fact, US has a relevant number of HCR affiliated to biotech firms). The European Union seems to do well, but its share of a fifth of the total is largely due to UK, Germany and France (Figure 5b). Again, this points to long-lasting European weakness in science, at least in top-notch and heavily cited fields, where American researchers enjoyed the lions share.

As already mentioned, the 2014 list witnessed a methodology change that does not allow for comparisons with the previous one (see Appendix B). The objective has not changed, since it still aims to single out the researchers who enjoy strong recognition from their peers. But the proxy used in the new list is the number of Highly Cited Papers published, which do not advantage disproportionally senior researchers. In our calculations, we considered only the primary affiliation of each researcher. This choice was made in order to avoid the emergence of biases towards the two countries that appeared to attract more scientists, namely the United States and Saudi Arabia. The HCRs being affiliated to a US research institution other than their primary one are 116; for Saudi Arabia, this number is 138. The striking differences between these two countries help explaining the very different dynamics taking place in the distribution of secondary affiliations. In fact, affiliation to a US institution is regarded as very prestigious, being offered to leading scholars or former alumni who started their career there. The case of Saudi Arabia is completely different and appears to be an example of some bad incentives put in place by international science evaluation. In the last decade, Saudi Arabia has made a decided commitment toward a future less dependent on oil revenues. As part of this turn toward the transformation into a world research leader, a new major university was founded with the name of King Abdullah University of Science and Technology (KAUST; see Mervis, 2009). However, despite massive displacement of resources, this strategy is deemed to pay off only in the medium-long term. Thus a second action was taken in order to rapidly improve Saudi Arabia's rankings in international comparisons, namely hiring already affirmed top researchers (Bhattacharjee, 2011). The selected scholars were asked only to add the name of the Saudi university as secondary affiliation on highlycited.com, possibly printing it on their papers too, and to be materially present in the institution for no more than a couple of weeks per year. In exchange, they received huge amount of money, either in the form of research grant or as an additional stipend. In a way, Saudi Arabia bought academic prestige for money, a phenomenon

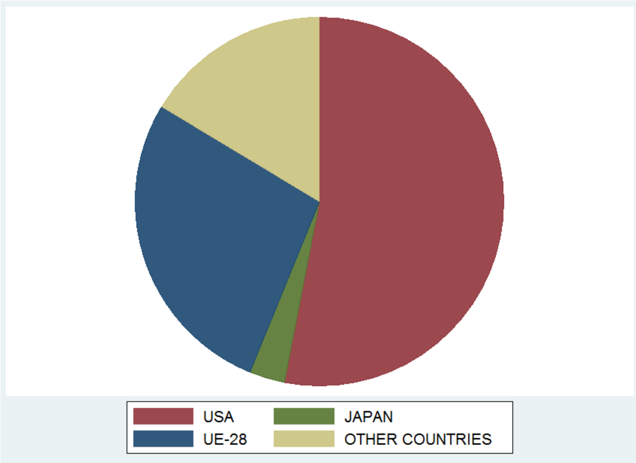
of additional names in the list.



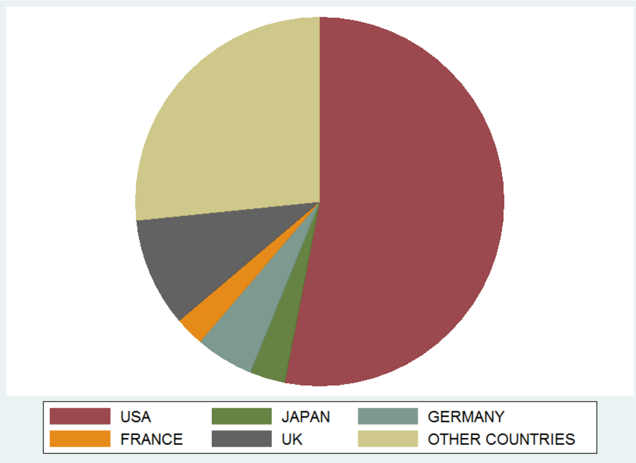
(a) (b)

Figure 5: Shares of Highly Cited Researchers by country of affiliation, 2001 list

Source: Thomson Reuters (Essential Science Indicators)



(a) precisare



(b) precisare

Figure 6: Shares of Highly Cited Researchers by country of affiliation, 2014 list

Source: Thomson Reuters (Essential Science Indicators)

that Gingras (2014) effectively labelled "dummy affiliations".[7]

Bearing in mind this discussion, data on primary affiliations are showed in Figure 6a and 6b. The comparison with the previous list on absolute values is not possible, but in relative terms we note that Europe displays a growing share of Highly Cited Researchers. This is due to the improving performance of European countries other than UK, Germany and France: while only accounting for 6% of the HCRs 2001 list, in the 2014 version they sum up to more than the 10% of the total. While implying that science is becoming more multipolar, Europe as a whole continues to lag behind the US, especially if one takes into account their different dimensions (as done in Table 3).

A major drawback of the European Paradox conjecture is its focus on total number of publications, without any correction for quality apart from the peer-review process described above (Dosi et al., 2006). The most popular way to ex post evaluate articles' impact is the number of citations received by other scientific works. In fact, with the term citation we refer to all the references to previous works present in a scientific article, whose objective is acknowledging intellectual debts. This way to quantify science quality suffers from several well-known shortcomings (Huang and Chang, 2008; Loscalzo, 2011; Van Noorden, 2010). However, studies show that on average the basic assumption of citations as proof of scientific relevance holds and can thus be used for careful comparisons (Bornmann and Daniel, 2008).

We explore this dimension of scientific production recurring to two kind of data: the number of papers published on Science and Nature and the quantity of Highly Cited Papers (HCPs) recorded by Thomson Reuters (Appendix B for the details). Our choice is due to the fact that this two indicators account for complementary dimensions of quality. The relevance of the former rests on the very long-standing prestige of the two journals, which throughout their existence maintained the highest standards in their editorial line. Any choice of the kind is deemed to result arbitrary, but Science (published in the USA) and Nature (UK-based) enjoy a prestige unquestionable. With reference to the second indicator chosen, Highly Cited Papers are selected with a rigorous process based only on citations received. The clarity of their selection procedure made this indicator more suitable than the variety of other quality proxies available, which rarely add information and only confound the analysis (Tijssen et al., 2002; Van Noorden, 2010; Bollen et al., 2009).

Figure 7 represents the share of articles accepted by the prestigious journals Science and Nature. The European catch-up takes a completely different flavour: while still marginally present, it almost ended in the last ten years. The United States maintains a long-standing leadership when it comes to the very top-journals. Latin America shows long-lasting weakness, with its share improving only marginally in recent years.

The very same conclusions are reached when plotting the share of Highly Cited Papers. Unfortunately, the timespan covered is shorted, because the Thomson Reuters data begin in 2005. However, the recent trend is clear: Europe is improving very slowly, and the credits go almost entirely to the Countries joining the Union recently, whose share of

[7]It must be recognized that their stratagy worked very well: now Saudi Arabia has four universities ranked into the first 500 in the world by the ARWU Shanghai index, while just eight years ago it had none.

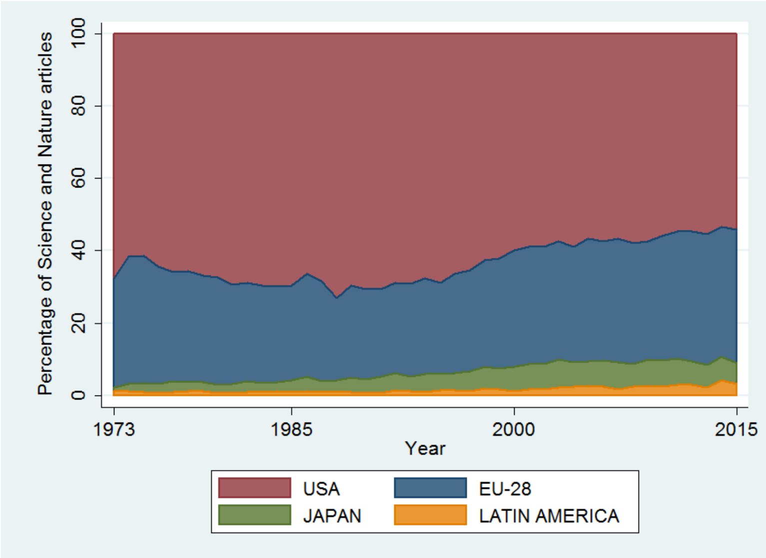


Figure 7: Share of articles published on Science and Nature, 1973-2015

Source: ISI-Web of Science (Core Collection)

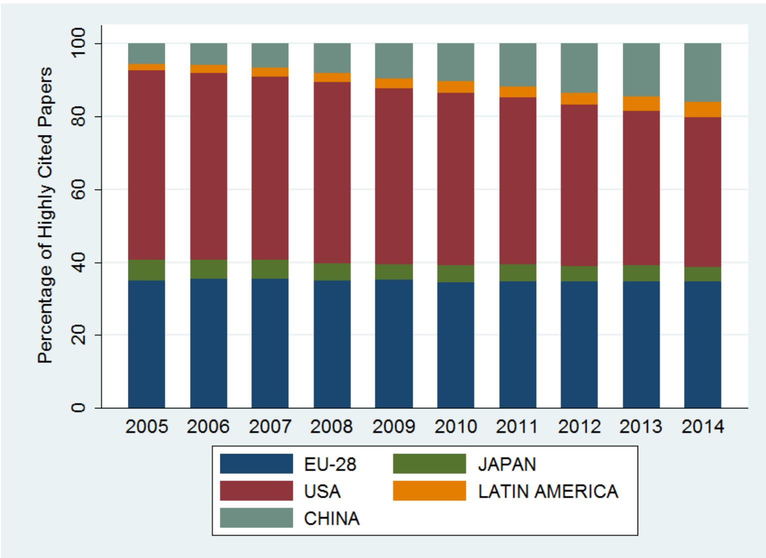


Figure 8: Share of Highly Cited Papers by affiliation country of the author, 2005-2014

Source: Thomson Reuters (Essential Science Indicators)

highly cited papers is rapidly growing at the expenses of the traditional leaders (Figure 9). Again, Japan and Latin America play a marginal role in the global picture.

A very interesting fact emerging from Figure 8 is the growing share of highly cited papers written by Chinese researchers. This is an important trend whose consequences are far reaching: China seems on the way of becoming a world scientific leader. Not only the total number of articles is increasing exponentially (Figure 2), but they are also of better quality. Figure 10 plots the ratio of highly cited papers per thousand of papers published on peer reviewed journals. China has a remarkable increase in this ratio, notwithstanding the contemporary growth of the total number of publications: on average, the quality of its research is improving faster, almost reaching the European levels. Nevertheless, the United States remain far ahead, with more than fourteen highly cited papers per thousand of articles.

A completely different story is taking place in Latin America, which remains at the border of the global scientific production. Nevertheless, the problem seems to be mainly related to the very scarce resources dedicated to scientific

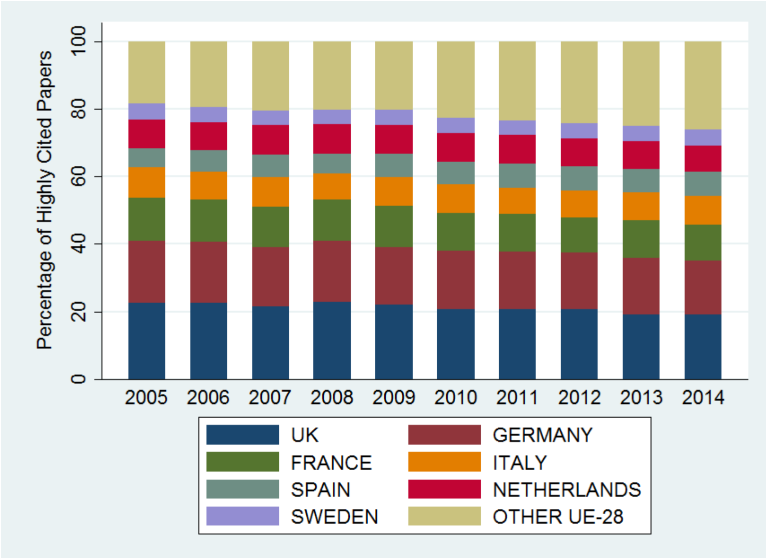


Figure 9: Share of Highly Cited Papers by affiliation country of the author within Europe, 2005-2014

Source: Thomson Reuters (Essential Science Indicators)

research. Productivity per researchers is not much lower than in Europe, and even the average quality of publications shows an encouraging ascending trend (Figure 10). A marked increase in the resources spent for scientific activity would probably allow Latin America to join the front running group of scientific superpowers.

To sum up, this broad overview shows a that no European paradox exists, at least in science. Europe still lags behind the United States in terms of top-notch research. With reference to Japan, it is very hard to evaluate his scientific performance simply from the data on English publication. It seems non-English speaking countries are the ones that suffer more from the linguistic bias. In fact, evaluating from the very high levels of inputs (both in terms of GERD and human resources), the very little number of English publications is an underestimate of its true science base. China, on the other hand, is rapidly putting aside its role of scientific follower, gradually approaching the scientific frontier that for more than a century has been prerogative of the triad EU-USA-Japan. Despite at a first glance this 'scientific big spurt' could seem lead by increases in sheer quantity, the number of highly cited papers is growing proportionally faster.

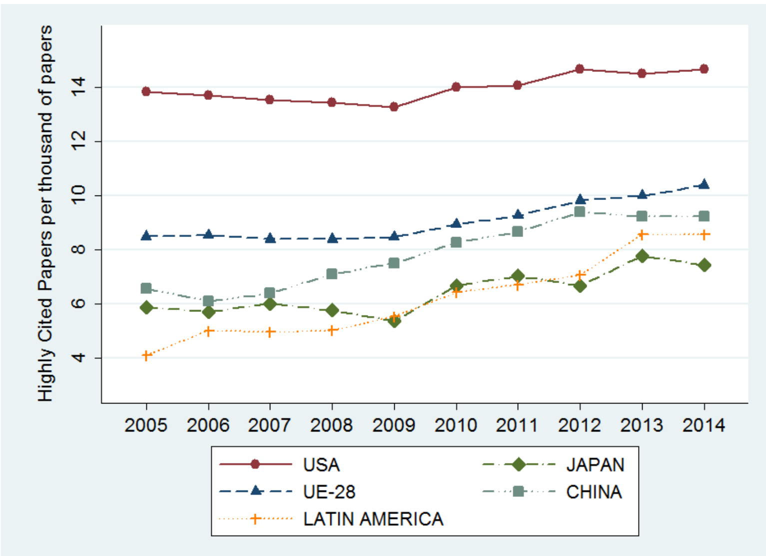


Figure 10: Share of Highly Cited Papers per thousand of papers published, 2005-2014

Source: Our calculations from ISI-Web of Science

Unlike Latin American countries, China has heavily invested in R&D expenditure, achieving good results.

With reference to the science base, if a paradox has to be found, this historical overview suggests that it is the sluggish European performance: despite twenty years of discussion and policies designed to transform the EU in the world 'most competitive and dynamic knowledge-based economy', not much has been achieved. The real European paradox is that all its policies aiming at improving its scientific performance has been by far less successful than the simple Chinese policy of expanding the resources dedicated to research. Instead of refusing to fund research that is not explicitly 'marketable', European policymakers should probably revert to the simple policy of investing more.

3.2 The historical evolution of technological performance

The dynamics of technology between 1840 and 2010 is investigated using patent data. In particular, we integrate two data sources in order to cover a long time span. The first data source is a novel dataset developed by Pan et al. (2016) that includes information on patents granted at the United States Patent and Trademark Office (USPTO) between 1840 and 1970. Interestingly, this data source has also information on the geographical location of inventors[8] and technological classes. In order to cover also recent years we use the EPO-PATSTAT Database (April 2014 version) to have figures on the period 1970-2010.

To zoom in on specific technological fields and industries we use the classification of US patent provided by Hall et al. (2001). This classification allows to assign each patent to six[9] macro technological areas to ascertain not only countries technological leadership but also possible differences in each country technological specialisation.

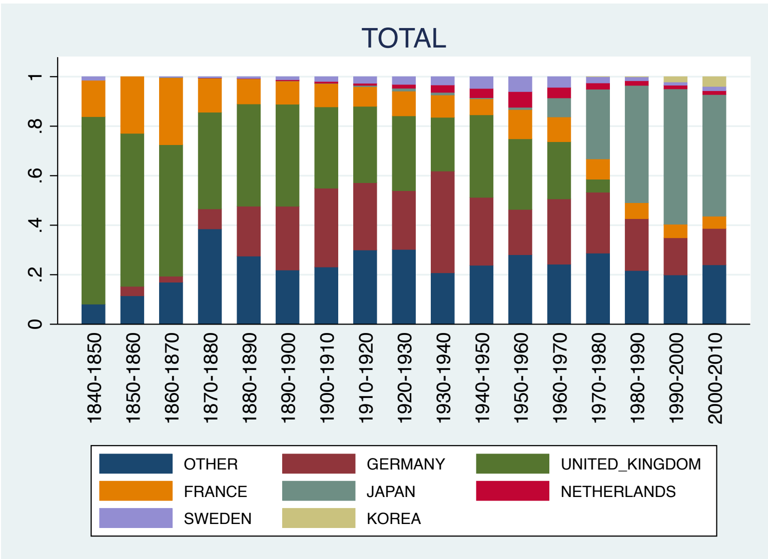


Figure 11: Country shares of USPTO patents over time

Figure 11 shows the distribution over time of the quotas of inventors located in specific countries. In order to avoid possible domestic biases we use the so-called "third country approach", this imply that the comparison of each country patent performance should be done in a (third) foreign patent office (Soete and Wyatt, 1983). In our case, this third patent office is the USPTO meaning that United States is not part of the picture. Of course, if on the one hand this choice permits to have comparable results, on the other hand it forbids conclusions on the technological leadership of United States.

Figure 11 highlights several interesting long term trend. First of all, it clearly shows the slow relative decline of United Kingdom as technological leader in favour of other countries such as Germany in the first half of the 1900s and Japan from the 1980s. Secondly, the figure highlights the incredibly rapid growth of Japan since the 1970s. Finally, the figure can shed some light on the overall geographical dispersion of innovative activities. In fact, the 7 considered

[8]For the methodological details see: `http://media.wix.com/ugd/ec2fa0_5600957f74b34ab59863fde9e9264094.docx?dn=PBR2016.docx)`

[9]We actually exclude from the analysis the last residual technological area labelled "Other" because of its heterogeneity.

countries always account for about 70% of all the foreign innovative activity in the United States. This result confirms that the finding of Patel and Pavitt (1991) on the high level of geographical concentration of innovation dates back to the 19th century.

Figure 12: Country shares of USPTO patents over time per technological area

Figure 12 display five sub-graphs to show the evolution over time of countries quotas over specific technological areas. Overall we see that the trends are consistent over time; however, some sectoral differences emerge. German technological catching up mainly relates to Chemical and Drugs technological areas, which is consistent with the historical account of the leadership of Germany being built upon the dye industry in the early 1900s (Chandler, 1992). On the contrary, recent Japanese technological success is mainly concentrated in the Electronics and Computer (Fransman, 1995) and Mechanics (Womack et al., 2007).

The last data presented in Figure 13 report the number of patents per capita between 1883 and 1993. These series are built using OTAF (Office of Technological Assessment) data; whereas population data are retrieved from Angus Maddisons website [10].

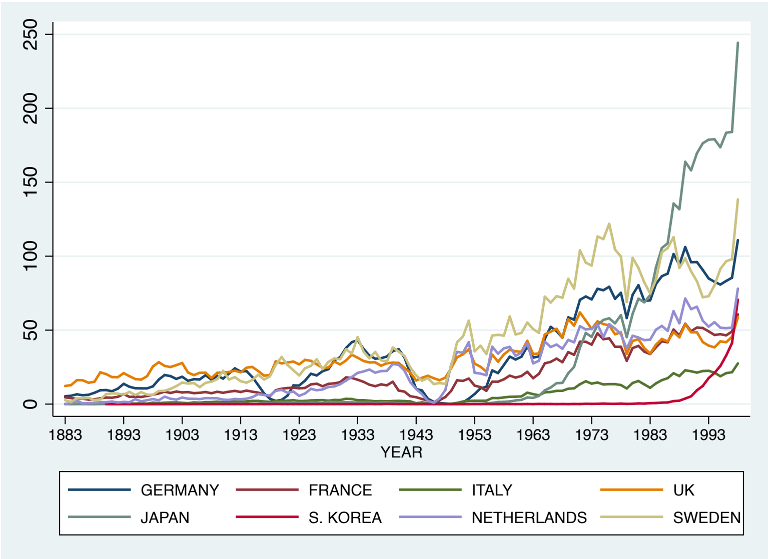


Figure 13: Number of patents per capita (Millions)

Figure 13 is rather confirmatory of the previous findings about the catching up of Japan and the recent success of Korea. Furthermore, it highlights the remarkable performance of Sweden over time. Finally, the figure also confirms previous findings (Nuvolari and Vasta, 2015) on the Italian trends. Italy represents an interesting case of “aborted” technological catching-up, where the increasing trend of patent per capita over the 1960 levels off and stagnate in the 1970.

4 Methodology

4.1 Factor Analysis

Factor analysis is an explorative technique that does not distinguish between dependent and independent variables, but it predicts factors on the basis of communalities (shared variance) among variables. In factor analysis the researcher can make the assumption of an underlying causal model aiming to find a few common factors linearly reconstructing the original variables. Factor loadings are then computed using the squared multiple correlations as estimates of the communality. Starting with the identification of how many factors retain, we recurred to the widely used so-called Kaiser criterion. Namely, it consists in retaining those factors whose eigenvalues are greater than 1.

Then, we perform factor analysis using the method of principal-component factor. The resulting loadings are rotated through an oblique “oblimim” rotation in order to help factor interpretation and make clearer patterns emerge from the results. Finally, we create factor scores on the basis of regression or Thomson and Bartlett scoring method, where factor scores are the coordinates of the original variables in the space of the factors. Because the difference between the two solutions is not too large, we decide to retain the Bartlett’s factor scores being slightly larger and helping to better define clusters in our results. We perform some post-estimation checks in order to assess the validity of factors retained, such as KaiserMeyerOlkin measure of sampling adequacy and Bartlett’s test of sphericity.

[10] Population data are available here: `http://www.ggdc.net/maddison/oriindex.htm`.

4.2 Cluster Analysis

Cluster analysis is a descriptive, a-theoretical and non-inferential technique allowing to define the structure of the data by placing similar observations in the same groups. Therefore, we perform a two-step cluster approach using the factors retained in the previous section as clustering variables. The two-step approach allows to firstly conduct a hierarchical procedure to detect the number of existing groups and then, a non-hierarchical clustering method having the advantage to reassign observations until maximum homogeneity within clusters is achieved (Hair (2010)). The hierarchical procedure facilitates the assessment of groups in our sample as it is carried out in a stepwise fashion and through an agglomerative method and allows to graphically evaluate the selected groups through a dendrogram. At the first stage, a single linkage clustering is performed computing the similarity between two groups as the similarity of the closest pair of observations between the two groups. A simple Euclidean measure is applied to compute distances between objects when forming the clusters. Selected clusters are those minimizing the increase in total sum of squares across all variables in all clusters. The Calinski-Harabasz pseudo-F stopping-rule index helps to identify the correct number of groups in the sample. Then, we perform a non-hierarchical clustering procedure based on k-means method. The non-hierarchical procedure assigns objects into clusters given the number of clusters and optionally same starting points. We try to perform the analysis with both specific cluster seeds and without assignment (random selection performed in STATA). The advantage of k-means algorithm is to divide data into the number of clusters detected in the first hierarchical analysis and then iteratively reassigning observations to clusters till the distance of observations in the same cluster is minimized and the distance between clusters is maximized. According to De Jong and Marsili (2006), the k-means method using randomly selected starting points seems to be quite weak compared to select k starting points. Therefore, we use the centroids of the initial hierarchical solution (k=3) as starting points. This procedure is strongly recommended by Milligan and Sokol (1980) and Punj and Stewart (1983). Finally as post estimation check, we perform MANOVA test in order to assess clustering variables validity and cluster stability.

4.3 Data Description

In order to undertake the empirical exercise and build a taxonomy of NSI, we construct an original country-level dataset. The variables included are only partially overlapping to the ones used by Fagerberg and Srholec (2008) and specifically focused on science, technology and innovation. In fact, one of the aims of this work is to contribute to broadening the dimensions taken in consideration when appraising in quantitative features of NSI. Thus we included in our analysis indicators usually not considered in the present context, or because their timespan is rather short and their availability is connected to recent years. Examples of such variables are: the Hausmann-Hidalgo indicator of economic complexity (Hidalgo and Hausmann, 2009), the indicator on university-industry collaboration from the Global Competitiveness Index dataset (WEF, 2016), and the Institutional Profile Database (MERIT, 2016). Furthermore, the dataset is also enriched by variables retrieved from innovation surveys carried out in different countries. Variables such as percentage of innovative firms, the percentage of firms declaring to introduce product and process innovations, and the relevance of internal and external sources of innovation allow to add to the analysis firm-level characteristics of the innovation process (Mairesse and Mohnen, 2010).

Given the focus of the project, the countries included in the analysis are: the EU28 members[11], 5 Latin American countries and 2 benchmark countries (United states and Japan). For Latin America we focused on Argentina, Brazil, Chile, Colombia, and Uruguay. This choice was mainly driven by their relevance in term of population, their innovative performance (as in the case of Uruguay whose economy is renewed for the good performance in semiconductors and software production), and data availability (we exclude Mexico for lack of comparability of innovation surveys).[12] We collected 22 indicators from different sources, covering the period between 2000 and 2013 (See Appendix C for the complete list and sources). However, for the empirical analysis we do not use yearly data but we compose a dataset taking for each country three observation in different point of time for each indicator. In order to expand the temporal coverage of the analysis at most, the first point in time is an average of the yearly data in 2000, 2001, 2002; the second point in time is an average of the yearly data in 2005, 2006, 2007; finally the third point in time is an average of the yearly data in 2010, 2011, 2012. The choice of these time-period is also derived by the timing of all the innovation surveys. In fact, if all the European countries are coordinates, this does not occur for Latin American countries. Finally,

[11] We also include in the analysis Turkey, Serbia, Iceland and Norway as data on innovation surveys are available in Eurostat.

[12] For details about comparability of Latin America surveys see Bogliacino et al. (2012).

the remaining missing data after the three years average were estimated using information on other indicators in the dataset and the impute procedure in Stata 13 (see Appendix D for a description of the procedure). For the details on the data sources of the innovation surveys data and their time-concordance with our three periods see Table 8 in Appendix C.

5 An empirical taxonomy of NSIs

5.1 Factor Analysis

Following the example of Fagerberg and Srholec (2008), we carry out an exploratory factor analysis to condensate the maximum amount of information available from the dataset of 21 indicators into a small number of composite variables.[13]

Table 4: Results of factor analysis (pattern matrix)

Variables	**Freeman**	**Lundvall**	**Nelson**	Uniqueness
Total number of patents	0.2249	-0.5028	**0.7082**	0.2805
Payments received for IPR	**0.7441**	0.1068	0.1640	0.2630
High tech exports	**0.6022**	-0.0394	0.1772	0.5321
Number of researchers	0.4627	0.2516	**0.4843**	0.1952
Gross expenditure in R&D	**0.6753**	-0.0383	0.4254	0.1474
Business R&D expenditure	0.0848	0.5719	**0.5986**	0.0879
Government R&D expenditure	-0.3525	**0.7337**	0.5237	0.1620
Domestic credit to privaate sector	**0.5467**	-0.0251	0.1687	0.6053
Economic complexity index	0.4172	0.2267	**0.5099**	0.2440
Human flight and brain drain	**-0.7428**	0.0319	-0.1637	0.3352
Social dialogue	**0.7579**	0.2946	-0.3275	0.3713
Long term State policy	**0.6592**	0.1942	-0.0297	0.4847
University-industry cooperation	**0.8085**	-0.2355	0.1399	0.2846
High tech public procurement	**0.8113**	-0.1892	0.0723	0.3322
Quality educative system	**0.7018**	0.0685	0.1116	0.4003
Innovative firms	0.1115	**0.8588**	0.2004	0.0683
Product innovation	0.2557	0.2025	**0.7369**	0.1051
Process innovation	0.1584	**0.9098**	-0.1209	0.1296
Organizational innovation	-0.0580	**0.9819**	0.0275	0.0479
External sources of innovation	-0.0494	**0.9531**	0.0176	0.1044
Internal sources of innovation	0.0300	**0.9730**	-0.0941	0.0735

Note: 74% of total variance explained. Extraction method: principal-axis factoring. Rotation: oblique.

The results reported in table 4 are sorted by the factor on which they show the highest loading. The solution suggested by the Kaiser rule is that three factors are enough in explaining a satisfactory deal of variance of the data, as shown in Figure 14.

The first factor is the most important one (it explains 29% of variance alone) and loads on the higher number of variables. It is characterized by high loadings on the more institutional variables of government policy, like the capacity of implementing a long term policy commitment or recurring to public high-tech procurement as a tool to foster innovation. Moreover, other two particularly important measures related to government policies fall within this factor, namely the quality of the education system and the extent of university-industry cooperation in research. Interestingly, some key indicators of technological development like the received payment for the use of IPR by foreigners and the R&D expenditures (as percentage of GDP) load highly on this factor. Considered together, these indicators encompass the peculiarities of the Japanese NSI as described by Christopher Freeman. In fact, the role of the state in coordinating

[13]See Appendix E for the descriptive statistics of the variables included.

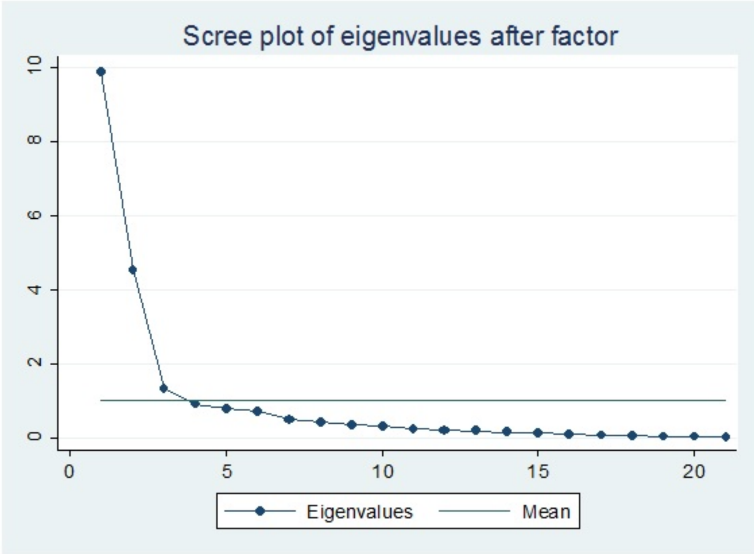


Figure 14: Scree plot of eigenvalues resulting from the data correlation matrix

innovation and the complementaries between firms and universities (for both research and educative purposes) constitute an important part of the Japanese successful story. To pay tribute to the scholar who first paid the due attention to this case study, we will refer to this as the "Freeman" factor.

The second factor loads very highly on specific aspects related to typology (process or organizational) and sources (internal or external) of firms' innovative activities. The proportion of innovative firms and the amount of public research undertaken are also covered. The group of variables in this factors seems to characterize a systemic innovative process centred on firms but where the government is an important actor through its efforts to advance the science base. This is indeed rather consistent with the Bengt-Åke's definition of NSI (and the Danish case) and therefore this factor is named "Lundvall".

The third and last factor correlates with indicators of scientific and technological investments, such as the number of researchers and the amount of R&D performed by private firms. In addition, this factor also encompasses some output indicators: the total number of patents, the Hausmann complexity index and the share of product innovation. The latter suggests the dominance of *technological competitiveness* strategies at the sector and country level more than *cost competitiveness*'s ones, indeed associated with the introduction of process innovations (Pianta and Vivarelli, 2003). Therefore, countries with a higher score of such factor develop industrial strategies of international competition relying on technological advances rather than cost compression. The technological capabilities captured by these variables are very near to the narrow definition of NSI put forward by Nelson and widely used throughout his 1993 book. Hence, we label this third factor "Nelson".

As we are working with a dataset characterized by three-periods time dimension, we can also look at how factor scores are differently distributed across countries and time[14].

Figure 15, 16, and 17 display 3D graphs that allow to simultaneously compare the positioning of each country according to their scores on the three dimensions. The comparison of the three graphs sheds some light on how the relative importance of each factor might change over time for each country.[15].

As Figure 15 shows, Japan and USA register the highest scores on the so-called Nelson factor followed by some Scandinavian countries. However, most European countries register high scores on the Lundvall factor as their positioning at the bottom of the graph suggests. At the same time, they largely vary in terms of Freeman's performance, going from the negative score of Bulgaria to the positive one of Luxembourg. As a general pattern, Europe is characterised by good

[14]See Appendix F for the changes over time of single factors in each country.

[15]As in Fagerberg and Srholec (2008) we standardize variables by deducting the mean and dividing by the standard deviation. We used the mean and standard deviation of the pooled data meaning that the change of a composite variable over time reflects both changes in each countrys position and changes in the importance of the underlying indicators. However, descriptive statistics of variables used in the factor analysis show that for all variables the between standard deviation is higher than the within standard deviation. Therefore, a careful attempt of factors' analysis over time can be made.

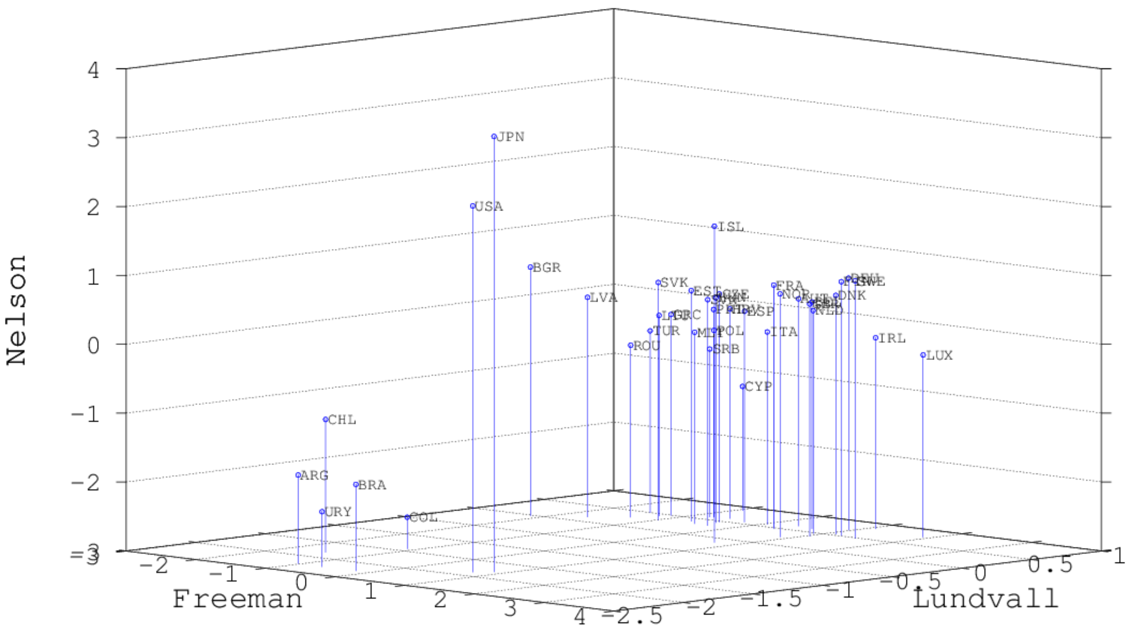


Figure 15: Factors' scores in period 1 (2000-2002)

degree of innovativeness - Lundvall factor -, poor science generation - Nelson factor - and heterogeneity in effectiveness of institutions and government policies - Freeman factor. Conversely, Latin American countries located at the bottom of the Lundvall axis are the poorest in terms both of science performance and innovativeness.

The comparative analysis of Figures 15 and 16 suggests a shift toward higher scores on the Freeman axis for some European countries such as Latvia and Bulgaria. However, the general score of European countries on the science factor has also changed toward lower values on the Nelson axis. This effect is even more evident looking at the 2010-2012 picture (Figure 17). Compared to 2005-2007 time span, the performances of Argentina and Brazil in science activities markedly improved. However, their positioning in terms of Freeman and Lundvall axis is almost unchanged and remain quite low, like the other Latin American countries. Finally, we register a decrease in Japan's science performance over the last period, leaving the leadership to the United States.

What is worth noting here is the effective empirical characterization of different NSIs that emerge from the factor analysis. The three dimensions captured account for the main aspects emphasized by Freeman, Lundvall and Nelson that we previously summarized in Table 2. Along with our tentative taxonomy of the theoretical definitions of innovation systems, the next step is providing an empirically-grounded description of several NSIs. Indeed, analysis of Figures 15, 16 and 17 underlines stability over time of our results and suggests the presence of a strong clusterisation across countries. We explicitly treat it in the next section, in order to formulate an empirical taxonomy of national innovation systems.

5.2 Cluster Analysis

On the basis of factor scores we perform a hierarchical clustering procedure on our sample selecting three groups. We retain the three clusters solution because it satisfies both cluster stopping rules (Calinski-Harabasz pseudo-F stopping-rule and Duda-Hart index). All four the MANOVA tests (Wilks lambda, Lawley-Hotelling trace, Pillais trace, Roys

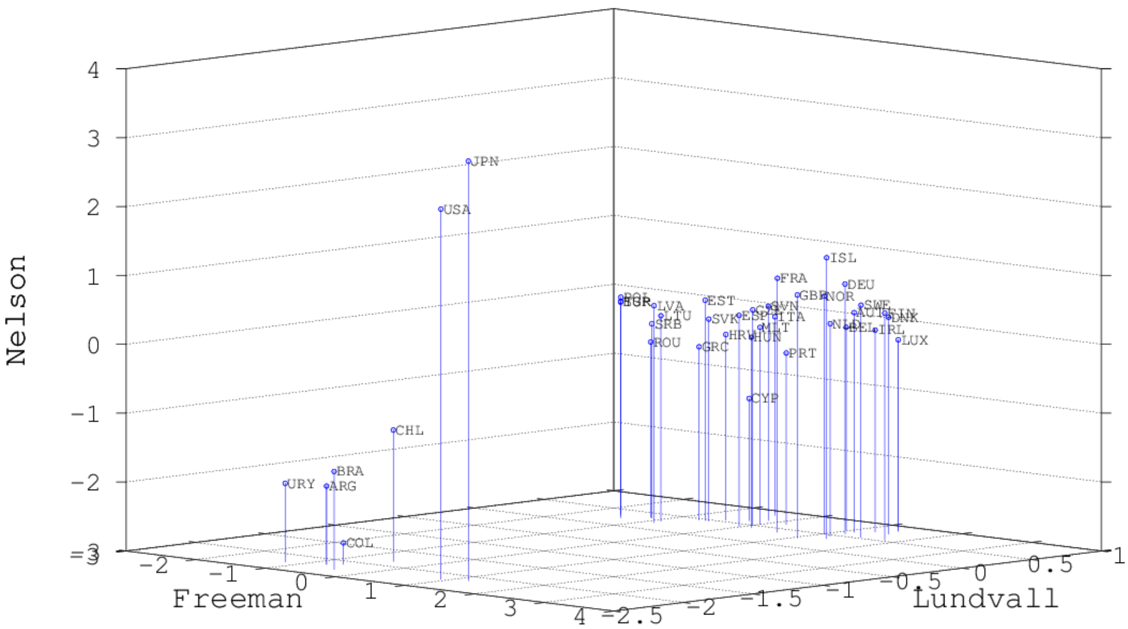


Figure 16: Factors' scores in period 2 (2005-2007)

largest root) reject the null hypothesis that the three clusters have equal means with respect to retained factors. Looking at the division of countries across clusters in Table 5 and the descriptive statistics of the main science, innovation variables as well as institutional proxies by cluster in Table 6, we define the existence of three main patterns of science, technology and institutional behaviours across the groups. The first cluster named *Leading Elite* encompasses US, Japan and the countries in Europe whose science and innovation performances excel compared to the others in the sample. The *Leading Elite*'s group has the highest mean value of private R&D on GDP - proxying the effort of business sector in R&D activities - as well as the highest number of ISO certifications and definitely the highest percentage of firms declaring to introduce product innovations. Countries in this cluster are the best performers in terms of science generation and high-tech productions. Therefore, the Leading Elite represents a NSI à la Nelson characterized by major science generation. In the second group that we define as the *Fragile Catching-up* cluster we find most of Southern and Eastern European countries lagging behind the *Leading Elite* both in science and technology performances. However, this cluster of countries is characterised by a relative high quality institutions and by a major presence of government policies directly intervening in the definition of science and technology programs. Technologies generation mainly concerns process and organizational innovations. Although on average almost half of the sample relies on internal sources of innovations, still on average 14% of firms declare recurring to external sources of innovations. The *Missed Opportunities* group clusters Latin American countries whose performances in science, technology and institutions are particularly low. With the exception of the enrolment rate (actually the highest detected in the sample due to strong government intervention in education programs of most Latin American countries), both technology and science indicators suggest low performances in science generation and technology production - as Table 6 shows.[16].

[16]High scores on education for the *Missed-Opportunities* group are confirmed looking at the gross tertiary enrolment rate for selected Latin American countries whose average is about 71.67% compared to 73% for high income countries (World Development Indicators, World Bank).

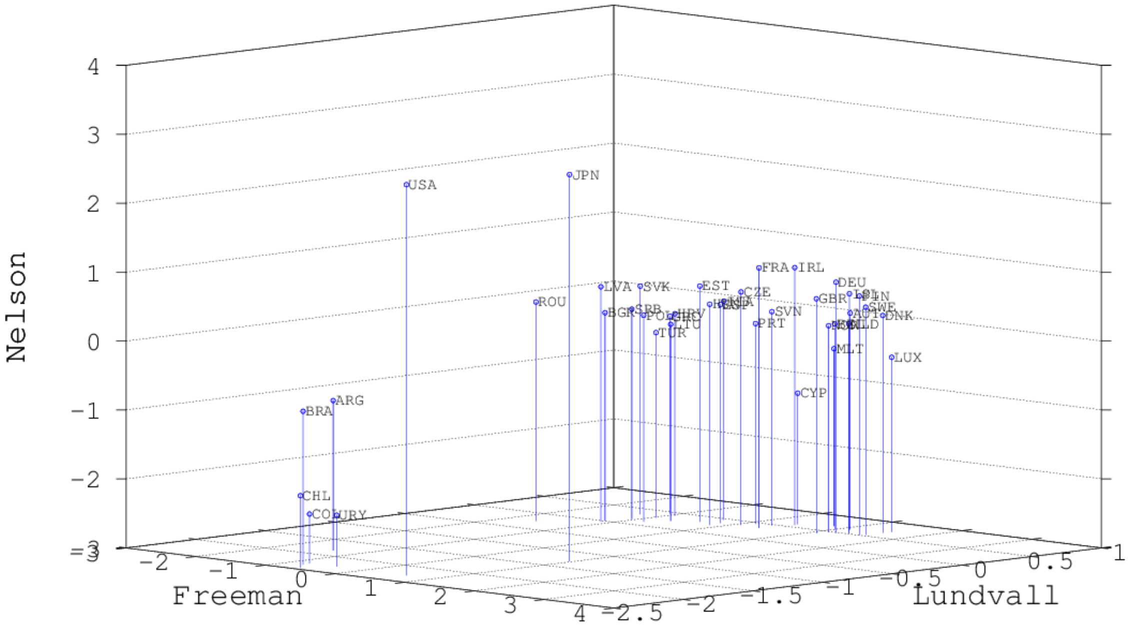


Figure 17: Factors' scores in period 3 (2010-2012)

Table 5: List of countries by cluster

Leading Elite	Austria, Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Japan, Luxembourg, Netherlands, Norway, Sweden, United Kingdom, United States
Fragile Catching-up	Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Serbia, Slovak Republic, Slovenia, Spain, Turkey
Missed Opportunities	Argentina, Brazil, Chile, Colombia, Uruguay

Table 6: Average differences of innovative indicators by cluster

Indicator	Leading Elite		Fragile Catching-up		Missed Opportunities	
	mean	sd	mean	sd	mean	sd
Total number of patents (per thousands of habitants)	0.4	0.78	0.31	0.44	0.36	0.54
IPR received (per thousands of habitants)	102965.46	292423.22	221974.78	373108.83	55985.52	118037.91
ISO certifications (per thousands of habitants)	0.53	0.45	0.52	0.32	0.18	0.19
Share of high-tech export on total export	14.44	12.97	15.68	10.2	10.13	9.39
Number of researchers (per million of habitants)	2656.07	1547.33	3101.86	2037.13	1447.53	1391.53
Share of R&D on GDP	1.45	0.93	1.42	0.93	0.9	1
Domestic credit to privates	87.07	56.77	85.54	61.63	70.55	63.22
Enrolment in tertiary education	3857.23	1048.18	3937.37	1237.48	4598.27	1330.88
Percentage of graduated in Engeeniring	13.72	4.25	11.82	4.81	13.57	5.49
Share of business R&D	44.22	18.57	43.74	18.79	21.9	26.92
Share of government R&D	37.04	16.22	37.83	15.33	21.95	25.41
Hausmann Complexity Index	1.18	0.78	1.13	0.55	0.36	0.74
Long term policy indicator	2.85	0.76	3.04	0.91	2.23	0.73
Collaboration University Industry	4.04	0.84	4.17	0.88	3.96	1.09
High tech public procurement	3.89	0.5	3.86	0.52	3.81	0.65
Quality of the education system	4.23	0.75	4.38	0.85	3.73	0.64
Share of firms introducing innovations	38.95	16.72	37.85	15.33	5.38	9.22
Share of firms introducing product innovations	9.18	5.7	9.59	5.03	2.35	3.55
Share of firms introducing process innovations	9.49	4.06	8.45	5.05	1.19	1.69
Share of firms introducing process innovations	47.25	17.89	39.32	13.64	8.07	13.52
Share of firms having external sources of innovations	13.31	5.64	14.39	6.2	4.14	6.58
Share of firms having internal sources of innovations	38.15	17.06	44.13	19.12	8.71	13.9
N	45		57		15	

In the next figures, we report the ranking of countries by cluster according to the selected factors that we define as Freeman, Lundvall and Nelson in the previous section.

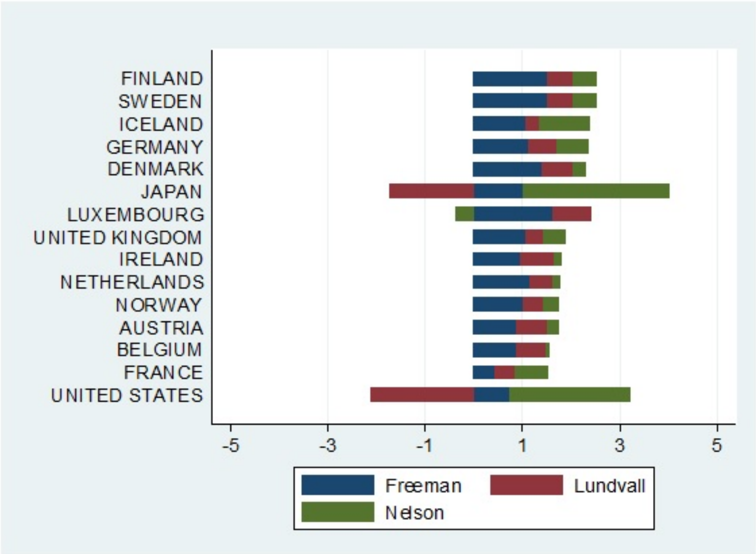


Figure 18: Leading Elite rankings

The *Leading Elite* is characterised by countries with positive scores across the three factors - Nelson, Freeman and Lundvall - with the exception of US and Japan with negative signs on institutional backgrounds. Overall, countries in this group are characterized by the best performances across the three dimensions, and US and Japan excel in science generation - Nelson factor -.

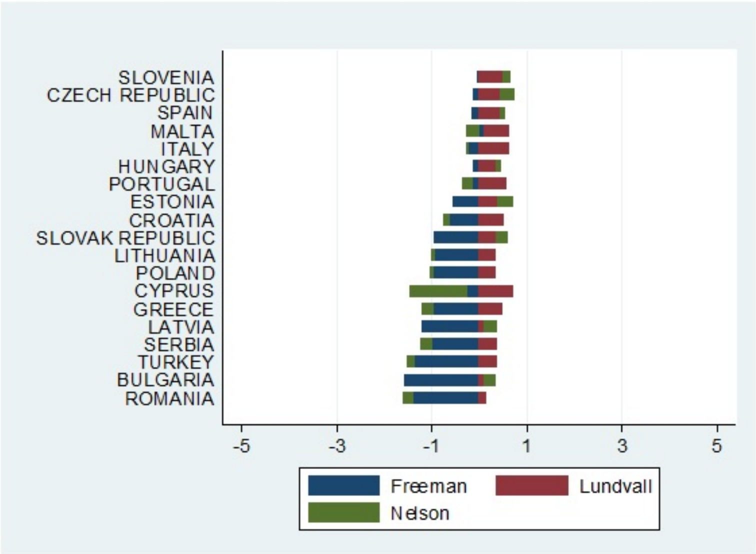


Figure 19: Fragile Catching-up rankings

For the *Fragile Catching-up* group, we detect positive scores across the three dimensions, however the science generation factor - Nelson - is strongly reduced compared to Lundvall and Freeman. It is worth noticing that Italy, Spain, Portugal and Greece are part of this group.

The *Missed-Opportunities* group clusters only Latin American countries that are in our sample the worst performers in science, technology and institutions. Indeed, the factor scores registered across the three dimensions are all negative. The lowest performance concerns the so-called Lundvall and Nelson factors. Colombia registers over time the worst performance across all dimensions and, specifically, for science generation.

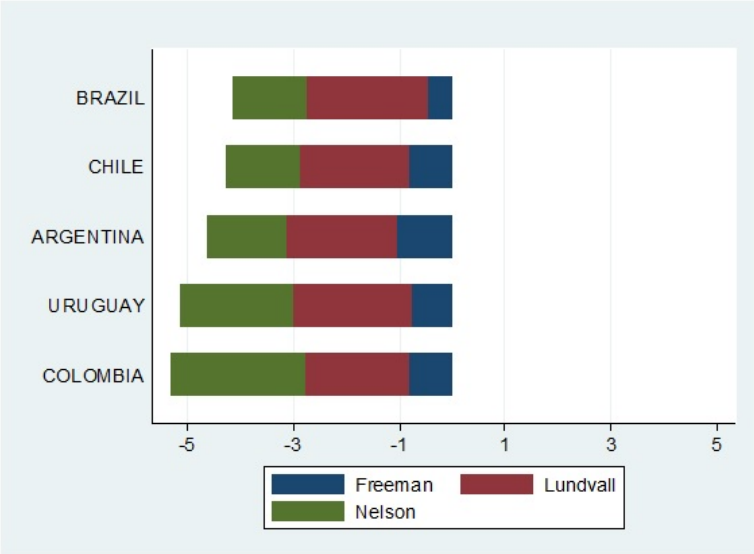


Figure 20: Missed opportunities rankings

6 Conclusions

The aim of this paper has been an empirical investigation of the innovative process of European economies in comparison with US, Japan and Latin American countries. In particular, departing from the qualitative literature (Nelson, 1993) on the existence of a variety of successful NSI we were interested in developing a taxonomy of countries sharing some similarities in their innovation capabilities. Therefore, we first revise the notion of NSI highlighting three conceptualisations of NSI corresponding to the seminal contributions of Nelson (Nelson, 1993), Freeman (Freeman, 1987) and Lundvall (Lundvall, 1992). Furthermore, framing on the NSI concept, we revise the main contributions on the so-called "European paradox" stating our research question on the existence of such paradox between science generation and technology application in Europe.

Building on these considerations, the aim of this article was twofold. First, we analysed the long term dynamics of science and technology at country level in order to understand the roots of the "minimal common block" to understand variety of NSIs among countries. Secondly, we contribute to the empirical literature on measurement of countries' capabilities (Fagerberg and Srholec, 2008, 2015a,b) by focussing on innovative capabilities and we propose a taxonomic exercise on different NSI.

The empirical analysis was carried out using a multidimensional indicators of scientific performance - such as articles published on peer-reviewed journals, number of Nobel prizes, number of highly cited researchers - to reconstruct the scientific history of European countries and some selected Latin American countries in comparison with US and Japan. Furthermore, we complemented the analysis on science dynamics with the evaluation of technological performances through a novel patent dataset. For the taxonomic exercise we used factor and cluster analysis on an ad-hoc country level database covering the 2000-2011 time span in order to group different types of NSIs.

Our results show that notion of European paradox is fragile. In science, Europe is actually still lagging behind the United States in terms of top-notch research. Despite possible language biases, evidence of scientific quality not based on publications (e.g. Nobel prize laureate) further confirms the today's leadership of US. The historical examination highlights that the US leadership has not been really challenged by all the European policies aiming at improving its scientific performance in recent years. Latin American countries have continued to play a marginal role in scientific production, mainly due to the lack of commitment and resources devoted to R&D. China is rapidly putting aside its role of scientific follower, thanks to a rapid growth in highly cited publications. On the technological front, Japan is the most successful story - no wonder that inspired Chris Freeman theorization of National Systems of Innovation. The novel patent data employed help tracing the emergence of Japan and, more recently, South Korea as major technological leaders. Within Europe huge variance persists, with the lion's share prerogative of UK and Germany. An interesting parallel can be traced between Sweden and Italy: the former exemplify the best growth performance during the Golden Age, while Italy has not been able to reach the technological frontier.

Concerning our taxonomic exercise, we first carried out a factor analysis on 21 variables characterizing and measuring different aspects of countries' NSI. The analysis of the variables included in the three factors extracted showed we could link each one to a specific conceptualisation of the NSI presented in the first part of the article. The co-existence of these three factors (labelled "Freeman", "Lundvall", and "Nelson", respectively) seems to suggests some complementaries among the three approaches mostly related to the broadness of the scope of what is relevant for defining the NSI. The first factor is consistent with Freeman's view as it scores highest values on institutional dimensions. The second one expresses the Lundvall dimension proxying a systemic perspective in which knowledge production is identified as a complex learning process involving different actors such as firms, universities, users, banks, etc. Lundvall's factor registers higher scores on government R&D and innovation outputs, mainly process and organizational innovations. Finally, the Nelson's factor reflects science and technology generation - proxied by total patents and researchers per million of inhabitants - and high-tech productions - proxied by higher scores on the Hausmann complexity index and the share of product innovations introduced.

As a second step of the analysis, we have clustered countries according to factors retained in the previous step defining the existence of three groups reflecting the relevance of the three NSI conceptualisations found. The first group of countries that we called "Leading Elite" cluster contain some European countries leading innovation and science processes, such as Austria, Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Sweden, United Kingdom and, of course, US and Japan. The "Leading Elite" groups the best performers in science generation, as the highest average number of patents demonstrates. In this cluster we find those countries standing at the frontier in terms of science generation, high-tech applications and indeed high quality institutional settings. The second cluster was dubbed "Fragile Catching-up" as it includes Eastern and Southern Europe countries. This cluster is characterized by high scores on government expenditure in R&D and low-tech productions. In fact, mostly of Eastern and Southern European countries focus their innovative activities to reduce production costs (i.e. process innovations or production technologies) implementing a growth model mostly based on cost competitiveness rather than technological competitiveness (Pianta and Vivarelli, 1999; Cirillo and Guarascio, 2015). Finally, the last cluster includes all the Latin American countries in the analysis (i.e. Argentina, Brazil, Colombia, Uruguay and Chile) that are characterized by poor performances in science and technology as well as weak institutional settings. This group has been labelled "Missed Opportunities" because they still display rather high levels of education (e.g. a high enrolment rate even in tertiary education) that might constitute the basis for some innovative activity. However, the extremely fragile institutional systems historically exposed such countries to short-term changes and volatility of macroeconomic conditions without fostering science generation or technology developments, as also emerged in our historical account of science and technology.

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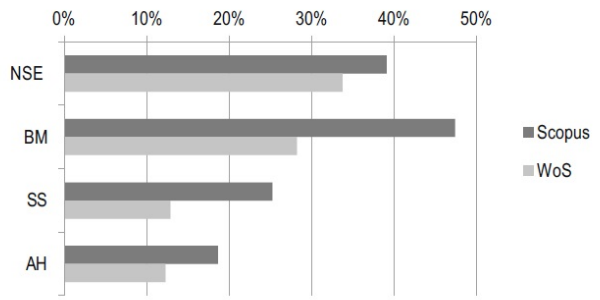
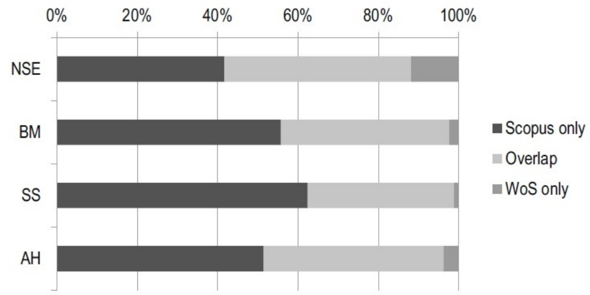
A Appendix

In order to collect the data on scientific publications we exploited the two most complete and renowned databanks in the field, namely Scopus (by Elsevier) and ISI-Web of Science (powered by Thomson Reuters). Mongeon and Paul-Hus (2016) provide a recent assessment of similarities and differences among the two, also critically discussing their shared shortcomings. The reference for total coverage is Ulrichs database, which is considered the most comprehensive worldwide list of periodicals (63,013 active periodicals listed). Starting with coverage, Scopus and ISI-Web of Science differ for the overall number of active journals included in their database (Figure 21). When they retrieved the data, they found 13,605 journals covered by Web of Science and 20,346 journals by Scopus. While large overlaps exist, Scopus provides a broader picture, while ISI is renowned for offering better coverage to titles back in time (at least until 1973). Both databases suffer from over-representation of certain countries and English articles, to the detriment of others languages (Van Leeuwen et al., 2001). Overall, journals published in some Western countries (United States, United Kingdom, Netherlands, France, Germany and Switzerland) represent a larger proportion of journals indexed in WoS and Scopus than they do in Ulrich. Moreover, there is a clear bias toward science and engineering with reference to social sciences or humanities (Mongeon and Paul-Hus, 2016). All these important limitations should be taken into account when assessing scientific activities.



(a) Proportion of Ulrich academic journals indexed in ISI-WoS and Scopus



(b) Coverage overlap of ISI-WoS and Scopus, by discipline

Figure 21: Comparison in journal coverage between ISI-Web of Science and Scopus

Source: Mongeon and Paul-Hus (2016)

The data collection strategy for both the databank is quite straightforward. Using the advanced research option, we searched the following string[17]:

```
Query 1# - to find ALL English articles published in a certain year and in a
certain country
DOCTYPE ( ar ) AND LANGUAGE ( english ) AND ( LIMIT-TO ( PUBYEAR , XXXX ) ) AND AFFILCOUNTRY (
XXXXXX )
```

As noted by several studies, collaboration among researchers is growing very fast in recent years. Adams (2012) documented that, *ceteris paribus*, a single issue of Nature has at least four times more authors than 60 years ago. In an influential analysis, Wuchty et al. (2007) found that papers written by research teams dominate the top of the citation distribution in several research domains. This growing trend in co-authorship is common both to hard and social sciences (especially in the fields involving quantitative analysis and thus strongly diverging in methods from humanities; see Henriksen, 2016). So, when dealing with co-authored papers, we faced the issue of consistently attributing them to the countries we want to compare. For every co-authored paper, all authors were assigned to the article, using the full counting method, which means that an article written by two researchers will count as one publication for each of them (as opposed to fractional counting in which case this article would be counted as 0.5 publication for each author). This

[17]The examples reported are the strings used to carry out queries on Scopus; for ISI-Web of Science, similar strings are not reported for space constraints.

in turn is reflected on countries scores, with an approach that advantages cross-country cooperation. However, when more than one author of a single paper was affiliated to the same country, the article just counted one for the country records. This is obviously the case of the European Union: when comparing France and Italy, a paper written by authors in Paris and Rome counts one for each country; but when comparing Europe with the United States, it just counts one.

The main issue when retrieving the data was the percentage of articles in the two database that were correctly classified with all the information about the author, his hosting institution and the journal of publication. What we found is that articles back in time are often not complete in these information. Therefore, many of them were not found in the results of our queries. This is not due to shortcomings in coverage of the databanks, but rather to the incompleteness of the information attached to the articles contained. In other words, the articles we were looking for are actually presents, but are not 'labelled with the information on the addresses of the authors and thus do not show up as a result of our queries. This is a problem we could not hope to solve, since due to deficits of the databanks. We nevertheless tried to broaden the analysis until covering the entire twentieth century, exploiting all the information available. The first step consisted in correctly understanding what kind of data we got from the queries. In order to find how many articles were correctly labelled (and thus being caught by the search keys), we recurred to the following very simple strategy. We got the number of articles whose address information was not missing by launching the query:

```
Query 2# - to find ALL the English articles published in a certain year
(irrespective of the affiliation country)
DOCTYPE ( ar ) AND LANGUAGE ( english ) AND ( LIMIT-TO ( PUBYEAR , XXXX ) )
```

Then, using wildcats, we obtained the number of articles correctly labelled for the affiliation country of the author:

```
Query 3# - to find ALL the English articles published in a certain year whose field Address is
specified
DOCTYPE ( ar ) AND LANGUAGE ( english ) AND AFFILCOUNTRY ( A* or b* or c* or d* or e* or f* or
g* or h* or i* or j* or k* or l* or m* or n* or o* or p* or q* or r* or s* or t* or u* or v* or
w* or x* or y* or z* or 1* or 2* or 3* or 4* or 5* or 6* or 7* or 8* or 9* or 0* ) AND ( LIMIT-TO
( PUBYEAR , XXXX ) )
```

The ratio between the number of articles resulting from these last two queries give us the percentage of articles published in a certain year and present in the platform that are correctly classified for affiliation country, thus allowing us to make country comparisons. The following Table 7 provides the comparison between ISI-Web of Science and Scopus.

Table 7: Comparison between ISI-Web of Science and Scopus

Publication year	% of English articles with the address field specified on the Scopus' year total	% of English articles with the address field specified on the ISI's year total (Core Collection)
2010	94.18%	97.09%
2000	88.12%	96.10%
1990	83.00%	95.39%
1980	76.49%	93.03%
1970	45.60%	11.45%
1960	38.11%	0.24%
1950	24.08%	2.39%
1940	57.48%	45.87%
1930	46.66%	38.31%
1920	44.02%	25.77%
1910	30.90%	24.80%
1900	18.81%	14.93%

Source: ISI-Web of Science (Core Collection) and Scopus. Data retrieved on March 23, 2016.

While the coverage of Scopus never reaches the very high levels of ISI-Web of Science, the latter shows a drastic decrease when approaching 1970 (in particular, the break is in 1972-1973). In light of these results, we decided to utilize Scopus for the comparisons going back to 1900. A big caveat remains, namely that we are making inferences and comparing share on subsamples of the total published articles. However, as far as we know, the pattern of articles missing the complete labelling is random, thus not advantaging one nation over the others. Moreover, many articles of first half of last century were published as anonymous reports, thus the percentage of missing is also increased by this. When coming to recent years, ISI performance is superior and its coverage almost total; hence, for analysis requiring a shorter timespan we utilized the date retrieved from it.

B Appendix

Throughout this work we exploited to two very useful dataset provided by Thomson Reuters, namely Highly cited papers and Highly cited researchers. The Highly Cited Papers (HCPs) indicator shows the volume of papers that are classified as highly cited in the Thomson Reuters service known as Essential Science Indicators (ESI). In a nutshell, the list only considers articles published in the last 10 years which are above a citation threshold different for each research field. Within each research field the best papers are then singled out, providing a benchmark indicator for research performance based on the top one percent published articles. Thomson Reuters made the list available since 2005.

The HCPs are then used to compile the Highly Cited Researchers (HCRs) list. The previous list of 2001 included researchers whose work received a total amount of citations above a certain fixed threshold, making the list biased toward older articles. Since 2014, a new methodology aimed at capturing the world top researchers in each subject area irrespective of their seniority has been adopted. The starting point is sorting the complete researchers list by number of HCPs produced. In order to decide how many of them will compose the highly cited list, the choice was selecting the a number of researchers for each field proportional to the dimension of the field itself. This procedure, along with several others minor correction, allowed for a fair repartition among the 22 fields. The only partial exception was Physics, where some papers display up to thousands of authors. Thus, articles with more than 30 institutional addresses were excluded by the counting. The resulting final list is made of 3,083 highly cited researchers.

C Appendix

This appendix reports the sources of data used in the analysis. Table 8 reports the sources of the surveys data and the concordance between the surveys timing and the three period considered in the analysis. Table 9 reports information about the data used for the factor and cluster analysis.

Table 8: Sources and timing of the surveys data

Country	**Name**	**Period Covered**	**Time**
EU28	CIS	1998-2000	1
		2002-2004	1
		2004-2006	2
		2008-2010	2
		2010-2012	3
Argentina	ENIT	1998-2001	1
	ENIT	2002-2004	1
	ENIT	2005	2
	ENDEI	2010-2012	3
Brazil	PINTEC Pesquisa de innovacao 2000	1998-2000	1
	PINTEC Pesquisa de innovacao 2003	2001-2003	1
	PINTEC Pesquisa de innovacao 2005	2003-2005	2
	PINTEC Pesquisa de innovacao 2011	2009-2011	3
Chile	Tercera Encuesta de Innovación Tecnológica	2000-2001	1
	Cuarta Encuesta de Innovación Tecnológica y Primera en Gasto y Personal en I+D	2003-2004	1
	Quinta Encuesta de Innovación y Segunda en Gasto y Personal en I+D	2005-2006	2
	Sptima Encuesta de Innovación en las Empresas	2009-2010	3
	Octata Encuesta de Innovación en las Empresas	2011-2012	3
Colombia	EDIT	2003-2004	1
	EDIT	2005-2006	2
	EDIT	2009-2010	3
	EDIT	2011-2012	3
Uruguay	Encuesta de Actividades de Innovación	1998-2000	1
	II Encuesta de Actividades de Innovación en la Industria	2001-2003	1
	III Encuesta de Actividades de Innovación en la Industria	2004-2006	2
	IV Encuesta de Actividades de Innovación en la Industria	2007-2009	2
	V Encuesta de Actividades de Innovación en la Industria	2010-2012	3

Table 9: Sources and definitions of data used in factor and cluster analysis

Indicator and definition	Scaling	Source	% missing
Research and development expenditure: expenditures for research and development are expenditures (both public and private) on creative work undertaken systematically to increase knowledge. R&D covers basic research, applied research, and experimental development.	% of GDP	World Bank - WDI database	2
Total number of patents: patent applications are worldwide patent applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention.	Per million of people	World Bank - WDI database	3
Brain drain: this indicator is one of the 12 constituting the Fragile State Index. It includes measures related to migration per capita, emigration of educated population, human capital.	Index (0-9)	Fund for Peace - Fragile Country Index Database	38
Social dialogue: capacity of dialogue and compromise different needs and necessity between firms owners and workers, or between social classes. Answer to the questions “Social dialogue effectiveness within companies” and “Social dialogue effectiveness at national level”	Index (1-4)	Institutional Profile Dataset - UNU MERIT	40
Number of total researchers: count of professionals engaged in the conception or creation of new knowledge, products, processes during a given year. Counted in full-time equivalents (FTE) in order to allow international comparisons.	Per million of people	UNESCO UIS database	4
Education system: executives’ answer to the question ”how well does the educative system in your country meet the needs of a competitive economy?” [1=not well at all; 7=very well]	Index (1-7)	GCI dataset - based on the WEF executive survey	36
Long term State policies: ability of the State to make a decision, coordination in the public sphere, cooperation of stakeholders . Answer to the questions “Are the actions of the public authorities in line with a long-term strategic vision? Do the public authorities have the capacity to encourage public and private stakeholders to work towards that vision? (through tax and financial incentives etc.)”	Index (1-4)	Institutional Profile Dataset - UNU MERIT	40
Government high-tech procurement: executives’ answer to the question “In your country, to what extent do government purchasing decisions foster innovation?” [1 = not at all; 7 = to a great extent]	Index (1-7)	GCI dataset - based on the WEF executive survey	36
Economic complexity: this index ranks how diversified and complex a countrys export basket is. A country is ‘complex’ if it exports highly complex and variegated products.	Index (rescaled)	Hidalgo and Hausmann database	11
High-technology exports: high-technology exports are products with high R&D intensity, such as in aerospace, computers, pharmaceuticals, scientific instruments, and electrical machinery.	% of manufactured exports	World Bank - WDI database	0
University-industry collaboration: executives’ answer to the question “In your country, to what extent do business and universities collaborate on research and development (R&D)?” [1 = do not collaborate at all; 7 = collaborate extensively]	Index (1-7)	GCI dataset - based on the WEF executive survey	36

Table 9: Sources and definitions of data used in factor and cluster analysis

Indicator and definition	**Scaling**	**Source**	**% missing**
Domestic credit to private sector: financial resources provided to the private sector by financial corporations (through loans, purchases of non-equity securities, trade credits).	% of GDP	World Bank - WDI database (2014)	0
Payment received from IPR: charges for the use of intellectual property are payments received by residents from non-residents for the authorized use of proprietary rights (such as patents and copyrights). Data are in current U.S. dollars.	Per thousand of people	World Bank - WDI database	17
Business R&D: the indicator provides the percentage of GERD (Gross domestic expenditure on R&D) financed by business sector.	% of GDP	EUROSTAT + RICYT	5
Government R&D: the indicator provides the percentage of GERD (Gross domestic expenditure on R&D) financed by government sector.	% of GDP	EUROSTAT + RICYT	5
Firms introducing innovations	% of firms' population	Innovation Surveys	10
Firms introducing product innovations	% of firms' population	Innovation Surveys	12
Firms introducing process innovations	% of firms' population	Innovation Surveys	11
Firms introducing organizational innovations	% of firms' population	Innovation Surveys	15
Firms declaring to have internal sources of innovations	% of firms' population	Innovation Surveys	21
Firms declaring to have external sources of innovations	% of firms' population	Innovation Surveys	21
ISO certifications: the number of ISO 9001 certificates (standards defining quality management and quality assurance program) issued to firms of a certain country.	Per thousand of people	International Organization for Standardisation (ISO Survey)	0
Percentage of graduates from tertiary education: the indicator express the total number of students graduating from Engineering, Manufacturing and Construction programmes in a given year (both sexes included).	% of total graduates	UNESCO UIS database	11
Number of students enrolled in tertiary education: in a given academic year, this indicator shows the general level of participation in tertiary education by indicating the proportion of students within a country's population.	Per 100,000 inhabitants	UNESCO UIS database	6

D Appendix

Lack of data conditioned our choice of indicators. But choosing only indicators with complete data for each country would have resulted in a much poorer dataset. Instead of recurring to listwise deletion or further reducing the number of country considered we followed Fagerberg and Shrolec (2008) and used an imputation technique.

The overall number of missings was slightly more than 17 percent of the dataset. Missing observations were estimated using the mi impute procedure in Stata 13 (for more information see Stata Multiple-imputation reference manual). The procedure, which is regression-based, uses information from other variables in the data set to fill in missing values. As made clear by the Figure 22, multiple imputation gives us several estimated values for the same missing entry recurring to some specific estimation model.

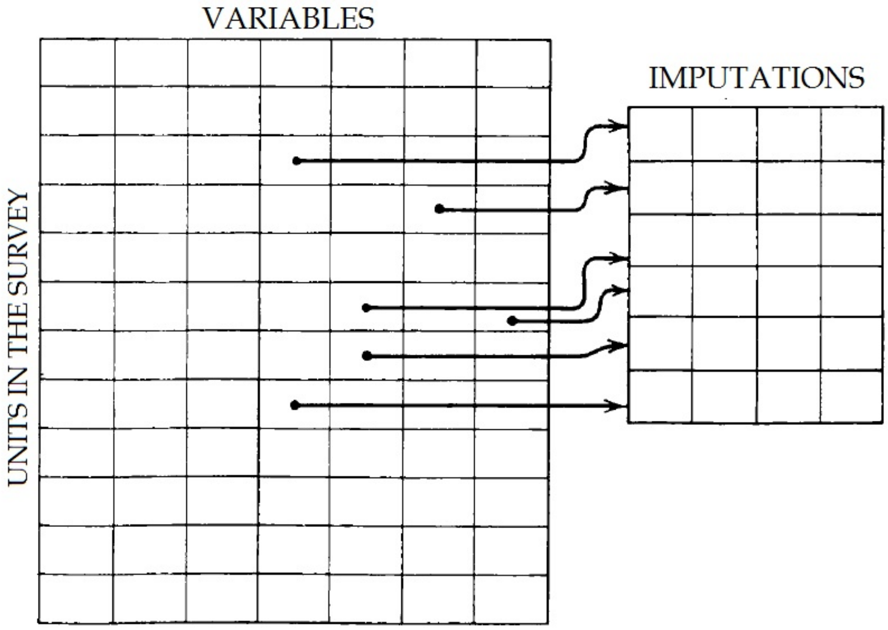


Figure 22: Dataset with m imputations for each missing data (Rubin, 1987 , p. 3)

We performed 20 imputations and used their averaged values to balance the final dataset. In a handful of cases the value was negative for indicators truncated at zero, so we replaced them with the minimum observed value for that indicator. Before the successive factor analysis, the dataset is transformed in logarithms (if necessary, a unity was added to avoid logs of zero). The reason for such a treatment is that variables expressed in logs are less sensitive to outliers, reducing the risk of getting results heavily influenced by a small number of observations.

Due to the relatively small number of data imputed, we did not expect any large bias to our analysis. Nevertheless, we carried out a robustness check by performing the factor analysis on the original dataset without the imputed values. The number of factors we would have retained was the same of the imputed dataset, explaining now 78% of variance.

E Appendix

Table 10: Descriptive statistics

Indicator	Mean	sd	Min	Max
Number of patents (per thousand of habitants)	0.35	0.6	0	3
IPR received (per thousand of habitants)	149684.13	319335.12	15.2	1801267
ISO certifications (per thousand of habitants)	0.47	0.38	0	2
Share of high-tech export on total export	14.48	11.31	1.7	64
Number of researchers (per million of habitants)	2734.71	1849.05	138.3	7619
Share of R&D on GDP	1.37	0.94	0.2	4
Domestic credit to privates	84.2	59.71	4.3	277
Enrolment in tertiary education	3990.89	1193.65	578.2	6645
Percentage of graduated in engeeniring	12.74	4.73	4.2	23
Share of business R&D	41.57	20.69	0.2	91
Share of government R&D	35.8	17.51	0.2	68
Hausmann Complexity Index	1.04	0.73	-0.3	3
Long term policy indicator	2.8	0.84	1	4
Collaboration University Industry	4.09	0.88	2.5	6
High-tech public procurement	3.86	0.52	2.7	5
Quality of educative system	4.24	0.81	2.9	6
Firms introducing innovations	34.57	18.52	0.2	71
Firms introducing product innovations	8.65	5.58	0.1	25
Firms introducing process innovations	8.09	5.02	0.2	28
Firms introducing process innovations	38.82	19.55	0	87
Firms having external sources of innovations	12.75	6.77	0.1	30
Firms having internal sources of innovations	37.56	20.75	0.1	96
Brain drain	3.55	1.79	1	9
Social dialogue	2.74	0.94	1	4
N		117		

F Appendix

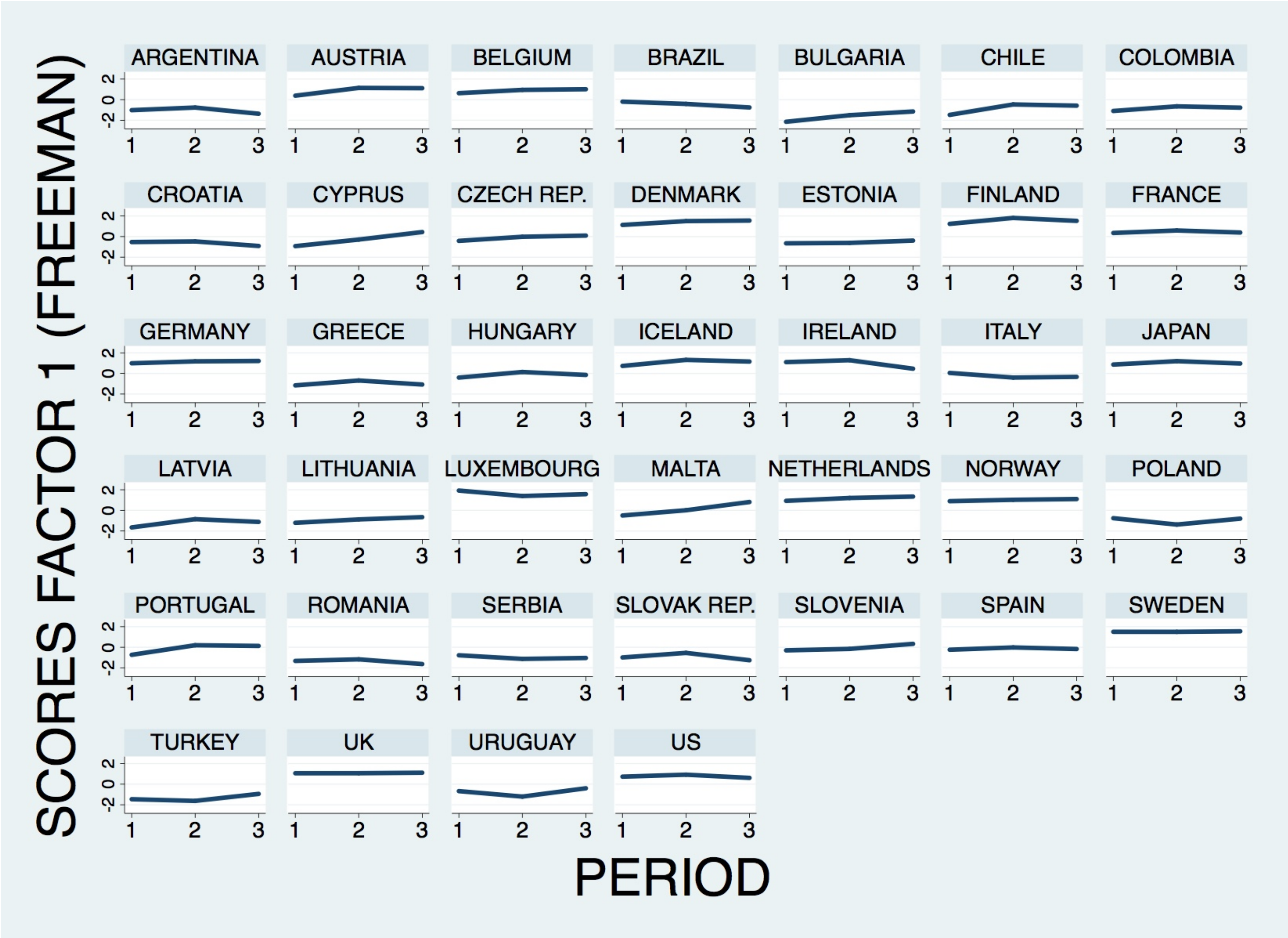


Figure 23: Freeman scores over time by country

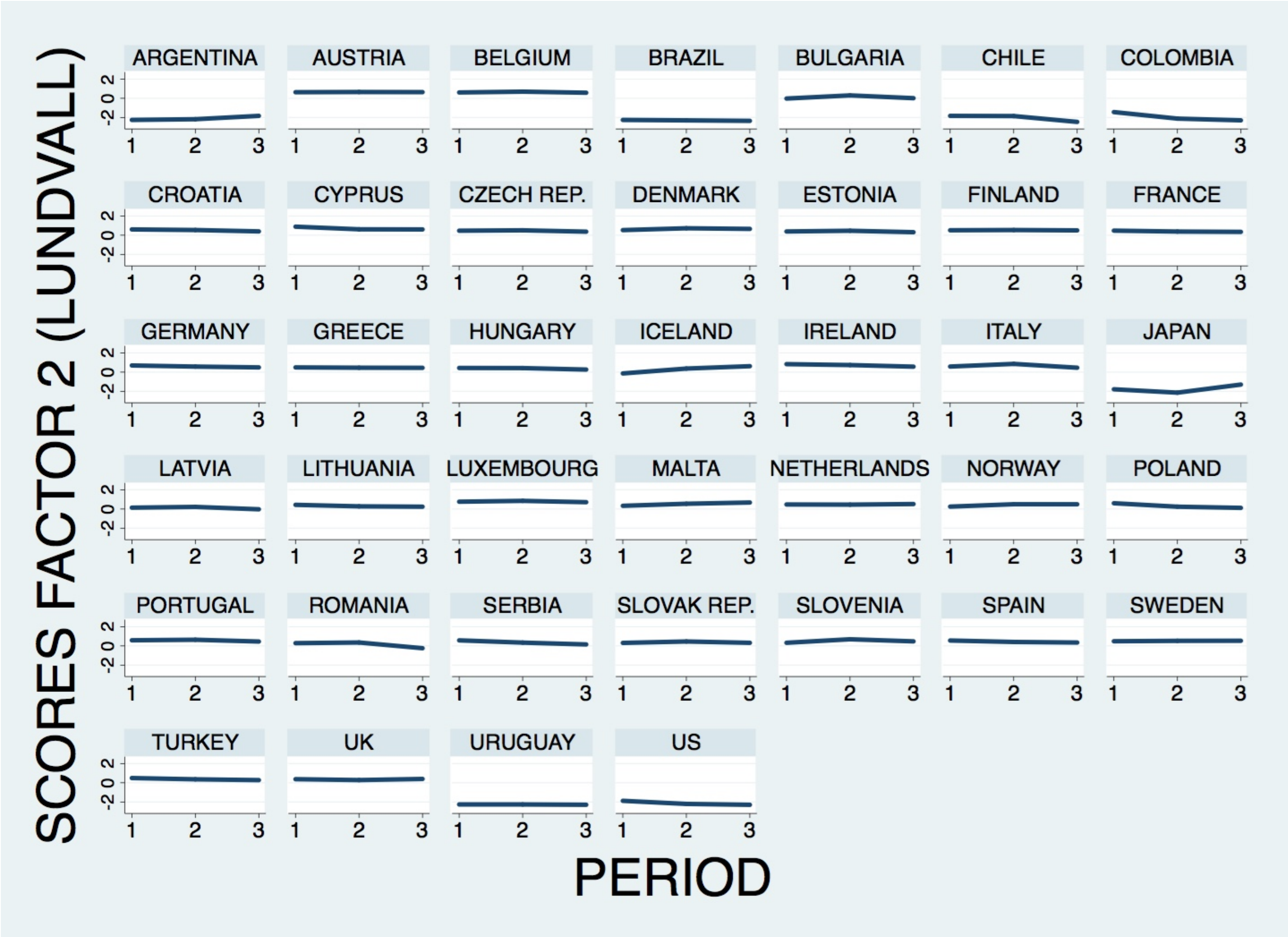


Figure 24: Lundvall scores over time by country

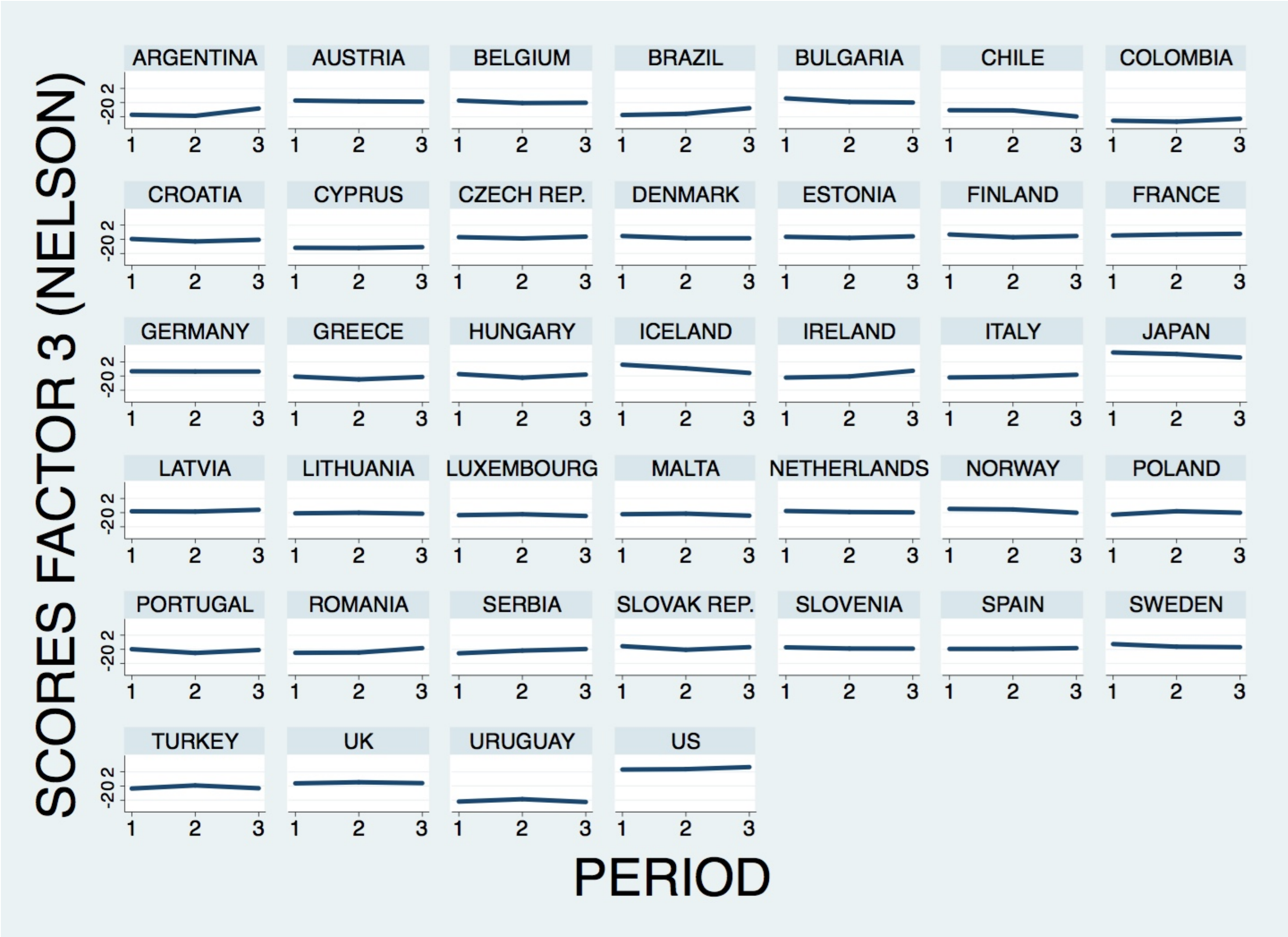


Figure 25: Nelson scores over time by country