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The end of the “European Paradox”

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Abstract This paper evaluates the European Paradox according to which Europe plays a leading world role in terms of scientific excellence, measured in terms of the number of publications, but lacks the entrepreneurial capacity of the US to transform this excellent performance into innovation, growth, and jobs. Citation distributions for the US, the European Union (EU), and the Rest of the World are evaluated using a pair of high- and low-impact indicators, as well as the mean citation rate (MCR). The dataset consists of 3.6 million articles published in 1998–2002 with a common 5-year citation window. The analysis is carried at a low aggregation level, namely, the 219 sub-fields identified with the Web of Science categories distinguished by Thomson Scientific. The problems posed by international co-authorship and the multiple assignments of articles to sub-fields are solved following a multiplicative strategy. We find that, although the EU has more publications than the US in 113 out of 219 sub-fields, the US is ahead of the EU in 189 sub-fields in terms of the high-impact indicator, and in 163 sub-fields in terms of the low-impact indicator. Finally, we verify that using the high-impact indicator the US/EU gap is usually greater than when using the MCR.

Keywords Citation impact · Research performance · US/European Union gap · High- and low-impact indicators · Mean citation rate

Introduction

The following two facts are well known. Firstly, since the mid 1990s the European Union (EU) namely, the 15 countries forming the EU before the 2004 accession has published

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somewhat more scientific papers in the periodical literature than the US. Secondly, as soon as one takes into account the citation impact per publication the relative situation of the EU and the US is completely reversed. Moreover, the EU performs particularly badly among highly cited papers.

Ignoring the second fact, the executive summary of the first REIST (Rapport européen sur les indicateurs scientifiques et technologiques) published separately in 1994 by Ugur Muldur and Luc Soete, launched the so-called "European Paradox", according to which Europe plays a leading world role in terms of scientific excellence, but lacks the entrepreneurial capacity of the US to transform this excellent performance into innovation, growth, and jobs. One year later, the European Commission Green Paper on Innovation popularized the idea. According to Delanghe et al. (2011, p. 394), although "the precise point the Commission wanted to make through the European Paradox concept … was often misunderstood"; "the idea generated much fruitful policy debate". As a matter of fact, in the academic literature we find rather different views about the first axes of the Paradox. For example, in his influential contribution King (2004) states that "the EU now matches the United States in the physical sciences, engineering and mathematics, although still lags in the life sciences". On the other hand, Dosi et al. (2009) conclude "no overall 'European paradox' with a lead in science but weak 'downstream' links is observed" [see also Dosi et al. (2006) and previous working papers]. The trouble with these two views is that King's statement refers to the share of total citations, which is a mere consequence of the European superiority in the volume of publications, while Dosi et al.'s conclusion is correct, but it is based on somewhat limited evidence. The issue is important, since an incorrect diagnosis can hardly lead to adequate policies.

Recent results in Albarrán et al. (2010), which contains a review of the official and academic literature, shed useful light on the question. That paper uses a large dataset, consisting of about 3.6 million articles published in 1998–2002, and indexed by Thomson Scientific. The paper compares the mean citation rate (MCR hereafter), as well as the publication shares of the US and the EU at every percentile of the world citation distribution in each of 22 broad scientific fields distinguished by Thomson Scientific. The evidence indicates that among the most influential articles, in 21 out of 22 fields the dominance of the US over the EU is overwhelming.

The mere percentage of articles satisfying some interesting condition only captures what can be referred to as the incidence aspect of the phenomenon in question. Albarrán et al. (2011a) introduced a novel methodology for the evaluation of research units of a certain size that overcomes this shortcoming. Using the dataset already described, Albarrán et al. (2011b) presented the first empirical application of this approach for the evaluation of the citation impact in three geographical areas: the US the EU, and the remaining countries grouped in an area referred to as the Rest of the World. It is found that the US performs dramatically better than the EU and the RW according to high- and low-impact indicators in all of the 22 fields already mentioned.

This paper addresses the following fundamental problem that limits the interest of the above results. It is well known that citation practices vary widely across scientific fields. Consequently, to ensure the maximum of homogeneity one should always work at the lowest aggregation level that the data allows for. However, as has been indicated, in our previous contributions we have worked at the level of the rather broad, heterogeneous fields originally distinguished by Thomson Scientific (Albarrán et al. 2010, 2011b, c). Thus, as pointed out by a referee "the results of the paper (Albarrán et al. 2011c) could be translated as that the US is disproportionally active in the highest impact subject category/-ies in all 22 fields". To verify whether the referee is right, this paper makes international comparisons at the sub-field level, where sub-fields are identified with the 219 Web of Science subject-categories also distinguished by Thomson Scientific. The citation impact of the US, the EU, and the Rest of the World is evaluated in terms of the MCR, as well as in terms of high- and low-impact indicators.

The rest of this paper consists of three Sections. " Methods, data, and descriptive statistics" presents the high- and low-impact indicators, as well as the data, and the methods used to assign articles to geographical areas and sub-fields. "Empirical results" presents the results about the US/EU gap using our preferred high-impact indicator, and the MCR. The "Appendix" contains some results at the sub-field level. "Conclusions" briefly describes some extensions, and offers some concluding comments.

Methods, data, and descriptive statistics

The Foster, Greer, and Thorbecke families of low- and high-impact indicators

It is well known that citation distributions are highly skewed in the sense that a large proportion of articles get none or few citations while a small percentage of them account for a disproportionate amount of all citations.[1] Albarrán et al. (2011a) introduced a novel methodology for the evaluation of research units of a certain size that begins with the observation that, due to their skewness, the upper and lower parts of citation distributions are typically very different. Consequently, it seems useful to describe a citation distribution by means of two real valued functions defined over the subsets of articles with citations above or below a Critical Citation Line. These are referred to as a high- and a low-impact indicator, respectively.[2]

In the first empirical application of this methodology, Albarrán et al. (2011b) use a family of high- and low-impact indicators originally suggested by Foster et al. (1984) that satisfies a number of desirable properties, including size- and scale-invariance. In view of the sub-field differences in size and MCR that we review in "Descriptive statistics" this is a very convenient property to have. For reasons of space, in this paper we focus on high-impact aspects.

Let $c = \{c_i\}$ be a citation distribution ordered from the least to the most cited article, where c_i is the number of citations received by the ith article. Given a certain Critical Citation Line, let $l\,(c)$ be the number of low-impact articles in distribution c with citations below the Line, and let $n\,(c)$ be the total number of articles. Given a citation distribution c and a Critical Citation Line denoted by z, the high-impact indicator H that will be used in the empirical section is defined by

[1] See inter alia Seglen (1992), Schubert et al. (1987) for evidence concerning scientific articles published in 1981–1985 in 114 sub-fields, Glänzel (2007) for articles published in 1980 in 12 broad fields and 60 middle-sized disciplines, Albarrán and Ruiz-Castillo (2011) for articles published in 1998–2002 in the 22 fields already mentioned, and Albarrán et al. (2011d) for these same articles classified in 219 Web of Science categories and a number of intermediate disciplines and broad scientific fields according to three aggregation schemes.

[2] Economists will surely recognize that the key to this approach is the identification of a citation distribution with an income distribution. Once this step is taken, the measurement of low-impact, which starts with the definition of low-citation papers as those with citations below the CCL, coincides with the measurement of economic poverty. In turn, once low-impact has been identified with economic poverty, it is equally natural to identify the measurement of high-impact with the measurement of a certain notion of economic affluence.

$$H(c) = [1/n(c)] \sum_{i=l(c)+1}^{n(c)} (\Gamma_i),\square$$

where $\Gamma_i = \max\{(c_i - z)/z, 0\}$ is the normalized high-impact gap. Note that $\Gamma_i > 0$ for high-impact articles, while $\Gamma_i = 0$ for low-impact articles. It can be shown that H increases with (1) the proportion of high-impact papers (incidence), (2) the average gap between the number of citations received by high-impact papers and the Critical Citation Line (intensity), and (3) the coefficient of variation of high-impact articles (citation inequality).[3]

The sensitivity of H to citation inequality contrasts with average-based indicators that are silent in this respect, with the axiom of Equal Impact of Additional Citations in Bouyssou and Marchant (2011), and even more with the measure suggested by Ravallion and Wagstaff (2011) that displays aversion to citation inequality. On the other hand, the version of the percentile rank approach used in the Science and Engineering Indicators of the US (National Science Board 2010) also includes a differential treatment of highly versus poorly cited publications that amounts to recognizing a positive role for citation inequality in research evaluation.

Assignment of articles to geographical areas, and to sub-fields

Since we wish to address a homogeneous population, in this paper only research articles or simply articles are studied. Our sample consists of 3,648,524 articles published in 1998–2002, as well as the more than 28 million citations they receive using a 5-year citation window for each one.

Articles are assigned to geographical areas according to the institutional affiliation of their authors as recorded in the Thomson Scientific database on the basis of what had been indicated in the by-line of the publications. The assignment of internationally co-authored papers among areas is problematic see inter alia Anderson et al. (1988). From a US geopolitical point of view, for example, we want to give as much weight to an article written in a US research center as we give to another co-authored by researchers working at a US and a European university. Thus, we side with many other authors in recommending a multiplicative strategy according to which in every internationally co-authored article a whole count is credited to each contributing area [see inter alia the influential contributions by May (1997) and King (2004), as well as the references in Section 2 in Albarrán et al. 2010]. Only domestic articles, or articles exclusively authored by one or more scientists affiliated to research centers, either in the US, the EU or the Rest of the World alone are counted once. In this way, the space of articles is expanded as much as necessary beyond the initial size arriving to what we call the geographical extended count. The total extended number of 4,142,281 articles is 13.5 % larger than in the original dataset (Aksnes et al. 2012 however, offer arguments in favor of using fractionalised rather than whole counts).

As indicated in the "Introduction", sub-fields are identified with the 219 Web of Science categories distinguished by Thomson Scientific. The difficulty is that in our dataset articles are assigned to these categories through the assignment of the journals where they have been published. It is well known that many journals are unambiguously assigned to one specific category, but many other typically receive a multiple assignment. This is an

[3] Albarrán et al. (2011a) contains a full discussion of the properties of high- and low-impact indicators, while Appendix II in the Working Paper version of this article, Herranz and Ruiz-Castillo (2011), contains a brief discussion of some of the more important properties.

important problem. For example, in the dataset used in this paper 42 % of the articles are assigned to two or more, up to a maximum of six sub-fields.

There are two ways to deal with this situation. The first follows a fractional strategy, according to which each publication is fractioned into as many equal pieces as necessary, with each piece assigned to a corresponding sub-field. The second procedure, followed in this paper applies a multiplicative strategy, according to which each paper is wholly counted as many times as necessary in the several sub-fields to which it is assigned Thus, if a paper is assigned to three sub-fields, it should be independently counted three times, once in each of the sub-fields in question, without altering the original number of citations in each case. In this way, the space of articles is expanded as much as necessary beyond the geographical extended count in what we call the double extended sub-field count, which in our case reaches 6,512,031 articles or 57.7 % more than the number of articles in the geographical extended count. However, this is not that worrisome in the sense that, since this strategy does not create any interdependencies among the sub-fields involved, it is still possible to separately investigate every sub-field in isolation, independently of what takes place in any other sub-field (see Herranz and Ruiz-Castillo (2012a) for a comparison of the two strategies).

Descriptive statistics

To save space, the information concerning the number of articles and the MCR at the sub-field level can be found in Table A in Appendix I in Herranz and Ruiz-Castillo (2011). For convenience, sub-fields are grouped into 20 aggregate categories and four very broad grand-fields that include Life Sciences, Physical Sciences, Other Natural Sciences, and Social Sciences.[4] Two points should be noted. Firstly, publication practices across sub-fields are known to be very different. Consequently, distribution sizes are expected to differ greatly. Specifically, in our dataset mean size is 29,735 articles and the standard deviation is 33,826. Secondly, given the differences in citation practices across sub-fields, MCRs vary also widely. The mean and standard deviation are 6.1 and 3.7. The maximum is reached in Cell Biology and Development Biology with 22.5 and 20.2 citations, while the minimum is in Engineering, Marine and Engineering, Petroleum with 1 and 1.2, respectively.

The share of all articles in the geographical areas is approximately 29, 33 and 38 % for the US, the EU, and the Rest of the World, respectively. More importantly, the EU has more articles than the US in 113 of 219 sub-fields or about 52 % of them [see columns 1–4 in Table B in Appendix I in Herranz and Ruiz-Castillo (2011)]. The allocation of these 113 sub-fields over grand-fields is as follows: 35 out of 77 sub-fields in Life Sciences, 30 out of 36 sub-fields in Physical Sciences, 47 out of 77 sub-fields in Other Natural Sciences, and only 1 out of 33 sub-fields in the Social Sciences. On the other hand, the correlation coefficients between the geographical areas' publication effort across sub-fields indicate that there is little difference in the way all areas allocate such effort [see columns 5–7 in Table B in Appendix I in Herranz and Ruiz-Castillo (2011)].

The Critical Citation Line is fixed equal to the 80th percentile of each sub-field distribution [see column 4 in Table A in Appendix I in Herranz and Ruiz-Castillo (2011)]. Critical values are always greater than the MCRs, but the difference is relatively small. On

[4] This is part of an aggregation scheme built in Albarrán et al. (2011d), which borrow from the schemes recommended by Tijssen and van Leeuwen (2003) and Glänzel and Schubert (2003) with the aim of maximizing the possibility that a power law represents the upper tail of each of the corresponding citation distributions. It is not claimed that this scheme provides an accurate representation of the structure of science. It is rather a convenient simplification for the presentation of information at the sub-field level in this paper.

average, the 80th percentile is reached at 8.8 citations, while the MCR is equal to 6.1. The reason is that the percentage of articles that receive citations less than or equal to the MCR at every aggregation level is on average approximately 70 % [see Glänzel (2007, 2010) and Albarrán et al. (2011a)].

Empirical results

High-impact results

Let $c = (c^1,\ldots, c^K)$ be the partition of citation distribution c into K geographical areas, indexed by $k = 1,\ldots, K$. Denote by $H(c)$ and $H(c^k)$ the high-impact indicators for the world as a whole and for k = US, EU, Rest of the World. To adequately interpret the results below, it is important to make it explicit that, from a normative point of view, for any area k it is preferable to have a high $H(c^k)$.

The index H is decomposable in the sense that the overall high-impact measure for a citation distribution c can be expressed as:

$$H(c) = \sum_k \omega_k H\left(c^k\right),$$

where ω_k is the area's publication share. In order to quantify the relative situation of any area in a given field, it is convenient to refer to the ratio $\omega_k H\left(c^k\right)/H(c)$ as area k's observed contribution relative to the overall high-impact level. We may ask what is this area's expected contribution to that level? The answer is, clearly, its publication share ω_k. Thus, the ratio (observed contribution/expected contribution) $= H\left(c^k\right)/H(ck)$ is greater than, equal to, or smaller than one as area k observed contribution is greater than, equal to, or smaller than this area expected contribution, namely its publication share ω_k. These contributions can be easily calculated with the information about $H(ck)$, and $H(c^k)$ provided in Table C in Appendix I in Herranz and Ruiz-Castillo (2011). A summary of results about observed contributions to high- and low-impact levels for the US and the EU is in Table 1. On the other hand, to assess the high-impact gap between the US and the EU in a given sub-field s, it is appropriate to use the ratios $H\left(c_s^{\mathrm{US}}\right)/H\left(c_s^{\mathrm{EU}}\right)$ which are in column 1 in Table D in Appendix I in Herranz and Ruiz-Castillo (2011). A summary of results about the US/EU gaps is in Table 2.

It can be observed that the contribution of the US to overall high-impact levels is below what can be expected from its publication share in only 11 out of 219 sub-fields. However, this is the case for the EU in 118 sub-fields (see the last two rows in Table 1). At the other extreme, the US and the EU contributions to the world high-impact levels is above 51 % of their publication shares in 95 and four instances, respectively (the four European instances are Urban Studies, Integrative and Complementary Medicine, Mining and Mineral Processing, and Engineering, Petroleum). Generally, the situation of the EU is particularly weak in the Life and the Physical Sciences. On the contrary, the US contribution to the world high-impact levels is more than 20 % above its publication share in 60 out of 77 sub-fields among the Life Sciences, and in all 36 sub-fields among the Physical Sciences.

What are the implications for the US/EU gap of the situation just reviewed? The EU is ahead of the US in 21 sub-fields within the Natural Sciences and nine within the Social Sciences (see the summary results in Table 2). The details are interesting. (1) Within Life Sciences, the EU is ahead in Biology [sub-fields 1 and 2 in Table C in the Appendix in

Table 1 Geographical areas' observed contribution to the overall high-impact level

	Observed contribution					
	Below its publication share	Above its publication share				
	(1)	0–20 % (2)	21–50 % (3)	>51 % (4)	(5) = 2 + 3 + 4	Total = 1 + 5
A. Life sciences						
US	4	13	33	27	73	77
EU	59	11	6	1	18	77
B. Physical sciences						
US	0	0	9	27	36	36
EU	22	10	4	0	14	36
C. Other natural sciences						
US	4	12	20	37	69	73
EU	35	25	11	2	38	73
Natural sciences = A + B + C						
US	8	25	62	91	178	186
EU	116	46	21	3	70	186
D. Social sciences						
US	3	14	12	4	30	33
EU	21	3	8	1	12	33
Total = A + B + C + D						
US	11	39	74	95	208	219
EU	118	49	29	4	101	219

Summary at the sub-field level

Table 2 Summary of the US/EU high-impact gap at the sub-field level

Number of sub-fields in which:	EU is ahead	US is ahead				Total
	(1)	0–50 % (2)	51–100 % (3)	>100 % (4)	Total (5)	(6)
A. Life sciences	8	21	30	18	69	77
B. Physical sciences	1	7	12	16	35	36
C. Other natural sciences	12	22	16	23	61	73
Natural sciences = A + B + C	21	50	58	57	165	186
D. Social sciences	9	7	3	14	24	33
Total = A + B + C + D	30	57	61	71	189	219

Herranz and Ruiz-Castillo (2011)], some behavioral sciences (sub-fields 65, and 66), Integrative and Complementary Medicine (sub-field 43), and a few sub-fields of lesser importance in Clinical Medicine III. (2) Within the 36 Physical Sciences, the EU is ahead only in Acoustics (sub-field 90). (3) Among the Other Natural Sciences, the EU is ahead in three Engineering sub-fields (120, 130 and 131), two in Materials Science (140 and 141), Mining and Mineral Processing (sub-field 155) in Geosciences, and five sub-fields in Agricultural and Environment and Plant and Animal Sciences. (4) Among the Social

Sciences, the EU is ahead in Linguistics, Geography, and Urban Studies (sub-fields 212, 200 and 203), as well as seven other lesser ones; a truly poor showing when it is compared with the record achieved by the US in the remaining 189 sub-fields. It suffices to note that in 57 natural sciences and 13 social sciences the US has a high-impact indicator at least twice as large as the one for the EU (see Table 2).[5]

The more frequent high-impact ranking has the US above the EU, and the EU above the Rest of the World in 166 sub-fields. However, the Rest of the World or the EU leads in publications in 136 out of 186 sub-fields in the natural sciences, but only in 2 out of 33 cases in the social sciences [see columns 1–4 in Table B in Appendix I in Herranz and Ruiz-Castillo (2011)]. This contrast should serve to conclude without further statistical analysis that the connection for any geographical area between having a large publication share in a given field and a good index of high-impact is practically non-existent. A different matter is the relationship between the publication effort devoted to the various sub-fields in each geographical area [columns 5–7 in Table B in Appendix I in Herranz and Ruiz-Castillo (2011)] and the high-impact levels achieved across sub-fields. The correlation coefficient between publication efforts and high-impact levels is only 0.036 for the US, 0.056 for the EU, and 0.011 for the Rest of the World. Thus, there is practically no connection between these variables.

The conclusion is inescapable a substantial publication effort by a geographical area in a given sub-field does not guarantee a good performance by this area in terms of a large high-impact level in that category. Similarly, a large volume of publications in specific sub-fields by any of the three large geographical areas does not guarantee a relatively good high-impact performance in those sub-fields. This is very damaging indeed for the proponents of a European Paradox, where the good health of European science is assessed in terms of large publication shares.

Average-based versus high-impact measurement of the US/EU Gap

Finally, we turn to the measurement of the US/EU gap in terms of average-based indicators. Denote by $c_s^k = \left\{c_{si}^k\right\}$ the citation distribution of area k in sub-field s, where c_{si}^k is the number of citations received by article i. Let $n\left(c_s^k\right)$ be the number of distinct articles that are assigned to sub-field s and have at least one author working in area k in the double extended sub-field count according to the multiplicative strategy. The MCR of unit k at the sub-field level s, M_s^k, is defined as:

$$M_s^k = \sum_i c_{si}^k / n\left(c_s^k\right).$$

Of course, at the sub-field level, i.e., at the maximum degree of homogeneity allowed by our data, for any k M_s^k is an acceptable indicator of the area's citation performance. Let

$$M_s = \sum_k \sum_i c_{si}^k / n(c_s) = \sum_k \left(n\left(c_s^k\right)/n(c_s)\right) M_s^k$$

be the world MCR in sub-field s. The average-based indicator for area k in sub-field s, A_s^k, is defined as

[5] It should be noted that, as far as low-impact, the EU situation is more favorable; its contribution to world levels is below its publication share in 137 out of 219 sub-fields. Furthermore, the US/EU low-impact gap reveals a weaker US dominance. It suffices to say that the EU is now ahead in 24 out of 73 Other Natural Sciences, and a total of 56 out of 219 sub-fields. Moreover, when the US is ahead, most of the time the gap is small. For the details, see Herranz and Ruiz-Castillo (2011).

$$A_s^k = M_s^k / M_s. \tag{1}$$

When A_s^k is above (below) one it means that the articles considered have received, on average, more (less) citations than the world as a whole. Of course,

$$\sum_k \left(n\left(c_s^k\right)/n(c_s)\right)A_s^k = M_s/M_s = 1.$$

The citation gap between any two areas k and v is measured by $A_s^k/A_s^v = M_s^k/M_s^v$. Table E in Appendix I in Herranz and Ruiz-Castillo (2011) presents the indicators A_s^k defined in Eq. 1 for all geographical areas and all sub-fields, as well as the measures of the US/EU gap, $A_s^{\mathrm{US}}/A_s^{\mathrm{EU}}$ which happen to be the ratios of the corresponding means $M_s^{\mathrm{US}}/M_s^{\mathrm{EU}}$. Sub-fields are ordered by the size of the US/EU gap within each field. These massive results are appropriately summarized in Table 3.

The resulting picture is quite dramatic: the US MCR is greater than that of the EU in 174 or almost 80 % of the 219 sub-fields (this percentage is slightly greater for the Natural Sciences). These sub-fields represent 92 % of all articles in the corresponding double extended count. In 105 sub-fields the US/EU gap is greater than 20 %, while in 31 sub-fields, representing about 15 % of all articles, the US/EU gap is greater than 40 %.

Column 3 in Table C in Appendix I in Herranz and Ruiz-Castillo (2011) includes the results about the US/EU gap according to the MCR, $M_s^{\mathrm{US}}/M_s^{\mathrm{EU}}$, while column 4 compares this measurement of the gap and the one using the high-impact indicator H. Recall that the MCR is defined over the entire range of citation values, while H is defined over high-impact articles with citations above the Critical Citation Line. Moreover, H is sensitive to the coefficient of variation, while the MCR is invariant to citation inequality [the situation is illustrated in fig. 1 in Herranz and Ruiz-Castillo (2011)], where sub-fields are classified into four large aggregates corresponding to Life Sciences, Physical Sciences, Other Natural Sciences, and Social Sciences.

From an ordinal point of view, there are few reversals in 21 cases the EU is ahead according to the MCR and behind according to the H index, while in six cases the opposite is the case. It should be noted that in only 24 sub-fields the US/EU gap is greater according to the MCR. From a cardinal point of view, differences between the results obtained with the two approaches are of a large order of magnitude: among the 195 sub-fields for which the US/EU high-impact gap is greater than the gap according to the MCR, in 110 cases the

Table 3 Comparison between geographical areas at the sub-field level according to the mean citation rate

Number of Sub-fields in which:	The US versus the EU				
	EU ahead	US ahead			Total
	(1)	<20 % (2)	≥20 % (3)	Total (4) = (2) + (3)	(5) = (1) + (4)
1. Life sciences	12	22	43	65	77
2. Physical sciences	1	14	21	35	36
3. Other natural sciences	21	26	26	52	73
4. Natural sciences = 1 + 2 + 3	34	62	90	152	186
5. Social sciences = 4 + 5	11	7	15	22	33
All sciences	45	69	105	174	219

difference is between 20 and 50 %, while in 32 additional cases the difference is greater than 50 %. The fact that the US/EU gap at the sub-field level in the double extended sub-field count tends to decrease when we measure it with the MCR is exactly what was found in Albarrán et al. (2011c) in the case in which articles are classified by Thomson Scientific into only one of 22 broad fields.

Conclusions

This paper has questioned the truth of the European Paradox according to which Europe plays a leading world role in terms of scientific excellence, measured in terms of the number of publications, but lacks the entrepreneurial capacity of the US to transform this excellence into innovation, growth, and jobs. The citation performance of the US, the EU, and the Rest of the World in 219 sub-fields, identified with the corresponding Web of Science categories, has been compared using two types of indicators a pair of high- and low-impact indicators introduced in Albarrán et al. (2011a) and the MCR. The dataset consists of 3.6 million articles published in 1998–2002 with a common 5-year citation window. A multiplicative strategy has been followed to solve the problems posed by international co-authorship and the multiple assignments of articles to sub-fields.

The European Paradox is definitely put to rest. It is true that the EU has more publications than the US in 113 sub-fields. Overall, the EU has 3.2 % more publications than the US. However, judging from the high-impact perspective, the EU is ahead of the US only in 30 out of 219 sub-fields. In 57 and 14 sub-fields within the Natural and the Social Sciences, respectively, the US has a high-impact indicator at least twice as large as the EU. When we measure the US/EU gap by low-impact indicators the EU situation is somewhat more favorable. For example, the EU is ahead in 56 out of 219 sub-fields. The paper has also compared the consequences of measuring the US/EU gap using the high-impact indicator or using the MCR. The gap is greater according to the latter only in 22 sub-fields. In the remaining 197 sub-fields the gap is considerably greater when measured by the high-impact indicator. At any rate, according to the MCR the US dominates the EU in 172 out of 219 sub-fields.

Several robustness tests have been performed (to save space, only a summary of results are included here). Firstly, in regard to the problem of the multiple assignment of articles to sub-fields, the paper has studied some of the consequences of using a fractional rather than a multiplicative strategy. The US/EU gap according to the MCR is strictly greater according to the fractional strategy in 137 sub-fields or 63 % of the total. However, gap differences are not very large: only in 20 cases, of which 17 reflect a worsening of the EU situation, this difference in absolute value is 10 % greater than the US/EU gap under the multiplicative strategy. As in Herranz and Ruiz-Castillo (2012a), the similarity of citation characteristics of articles published in journals assigned to one or several sub-fields guarantees that choosing one of the two strategies may not lead to a radically different picture in this practical application. Secondly, after raising the Critical Citation Line from the 80th to the 95th percentile of world citation distributions the EU is ahead of the US in exactly the same number of sub-fields as before, namely, 30. The main difference is that the US dominance in the remaining 189 sub-fields is somewhat greater. For example, the 71 cases in which the US high-impact indicator was more than 100 % greater than that of the EU when the Critical Citation Line was fixed at the 80th percentile now become 99. Nevertheless, the impact of raising the Critical Citation Line is also of a small order of magnitude.

The problem with the European Paradox is that it is exclusively based on the number of publications. However, as already pointed out in Albarrán et al. (2010, 2011b, c) for the 22 broad fields distinguished by Thomson Scientific, this paper confirms that there is no connection between publication shares and high- or low-impact levels. As a matter of fact, geographical areas do not seem to specialize in the sub-fields where they enjoy a comparative advantage measured by the $A_s^k = M_s^k / M_s$ ratio. The correlation coefficients between this indicator and the ratio of an area's to the world's publication effort are −0.52, −0.08 and −0.13 for the US, the EU, and the Rest of the World, respectively. Forces explaining publication efforts are different from the ones explaining relative success measured by citation impact.

In this scenario, although the EU often publishes more articles than the US, the fundamental fact is the overwhelming dominance of the US over the EU. Likewise, although the Rest of the World usually is the area with more publications, it exhibits the worst citation performance in almost all cases. In brief, this paper has established that the European Paradox masks a truly European Drama: judging from citation impact at the lowest aggregation level, the dominance of the US over the EU in the basic and applied research published in the periodical literature is almost universal.

The present analysis might be extended in several directions, of which we will mention only three. Firstly, although working at the sub-field level is essential, for many practical problems the interest of investigating larger aggregates is undeniable. This task poses the well-known problem that aggregation procedures should correct for differences in citation practices across sub-fields. In Herranz and Ruiz-Castillo (2012a) we suggest a novel normalization procedure for the multiplicative approach, while in Herranz and Ruiz-Castillo (2012b) we apply this procedure for the first time for the evaluation of the US, the EU, and the Rest of the World using both average-based and high- and low-impact citation indicators. Secondly, it should be noted that our high-impact indicator is not robust to the presence of a handful of articles with a truly phenomenal number of citations. Therefore, it would also be interesting to explore the European Paradox using indicators of citation excellence robust to extreme observations. Thirdly, before policy recommendations can be suggested the results in this paper should be extended towards specific countries within the EU and the Rest of the World, and even individual research centers. It would be important to analyze domestic and internationally co-authored articles separately. In the European case, the latter should differentiate between intra-European cooperation and cooperation with the US and the Rest of the World.

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