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Abstract

Using a data set of highly cited researchers in all fields of science, we show that the gap in scientific performance between Europe, especially continental Europe, and the USA is large. We model the number of highly cited researchers in a sample of countries as a function of physical and human capital and a country-specific, factor-augmenting Hicks-neutral productivity term. We find that differences in productivity between Anglo-Saxon countries and other countries are not solely due to differences in the levels of inputs. Not surprisingly, our results reveal the importance of English proficiency. However, they also show that the governance and design of research institutions that characterize Anglo-Saxon countries, as well as a few other countries that have similar institutions, is another critical factor for research output.

Keywords: research performance, citations, knowledge economies, university governance.

JEL Classification: I23, C25

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1 Introduction

The title of this paper is inspired by the famous play "The Resistible Rise of Arturo Ui" written (in German) by Bertolt Brecht in 1941. In choosing this title, Brecht intended to say that the rise of Fascism in Europe was not inevitable. We have the same view of the decline of European science. Is there really such a decline? This is what this paper is about.

To support our view about the unsatisfactory state of European science, we exploit a data set made freely accessible by Thomson Scientific on the Web site ISIHighlyCited.com. This site gives the top research professionals working in a variety of occupations by name, category, country, and institutional affiliation for 21 disciplines listed in Table 1. In a nutshell, $5,790$ researchers, $1,329$ institutions and 41 countries are considered.[1] For each discipline, the 250 most highly cited researchers (in short, HCRs) have been selected from 1981 to 1999 (in fact, the actual number of HCRs often slightly exceeds the benchmark number of 250). To build the database from which HCRs are selected, Thomson Scientific considers all the papers belonging to its 21 scientific citation indices, and which have been *both* published and cited during the period 1981-1999. This data set spans a sufficiently long period of time to make this sample representative of the current state of scientific research in the whole world. Furthermore, we believe that the number of citations is a good proxy of the quality of research output in that it measures the long run impact of publications on the scientific community. Note also that this data set is one of the main inputs used in building the Shanghai world ranking of universities.[2]

In Section 2, we provide a synthetic account of the information available on the site ISIHighlyCited.com, using simple tools such as statistics, figures and tables. The main striking feature that emerges from this analysis is the *massive* dominance of American universities that account for two thirds of the sample, whereas the European universities stand for only 22.3%.[3] Within the European Union, national disparities appear to be huge with a handful of countries doing much better than the others.

Quite naturally, this state of affairs leads us to raise the following question: how can it be explained? This is what we undertake in Section 3 where we develop an econometric study that aims at uncovering the main explanatory variables for the very uneven distribution of top researchers.

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[1] Note that $5,597$ people are associated with an institution. The difference comes from those who have changed affiliation too often to be associated with a particular institution or have passed away before 1999.

[2] Admittedly, the number of patents is another important scientific output of universities. Yet, we believe that publications are the main criterion used in most academic institutions to evaluate the research activities of professors and researchers.

[3] Additional arguments to those developed in this paper may be found in Aghion et al. (2007).

Using a knowledge production function whose inputs are R&D expenditure and human capital, we find not surprisingly that these two variables are significant. The country-specific factor-augmenting productivity term depends on per capita GDP as well as on two non-economic variables, i.e. English proficiency and colonial ties with the UK. These three variables also contribute to explain the differences across countries. This was expected for per capita GDP. English proficiency explains, at least partially, the good performance of English-speaking countries as well as that of a few other countries in which the population has a very good knowledge of English. Colonial ties with the UK have a different nature. This variable aims to capture the bundle of specific factors related to the governance and organizational design that characterize (more or less) all Anglo-Saxon universities, and which have been duplicated in a few other countries. In this respect, our analysis agrees with recent contributions in economics that show how the design and quality of institutions matters for economic growth and development (Guiso et al. 2004; Bennedsen et al. 2005; Persson and Tabellini, 2006). Section 4 concludes the paper.

Before proceeding, the following comment is in order. Our approach vastly differs from that taken up by the Times Higher Education Supplement (THES) in its ranking of the top 2000 universities (Tulkens, 2007). THES gives a weight equal to 0.2 to the data used in this paper. The objective of THES is broader than ours as we do not focus on teaching. However, it is our contention that the approach followed here provides a sharper description of the research output of universities. This is confirmed by Van Raan (2005) who finds that the correlation between expert-based rankings, which have a weight equal to 0.4 in THES, and bibliometric outcomes is almost zero.

2 Where do we stand?

The distribution of HCRs across institutions is very uneven. Figure 1 depicts the cumulative distribution, a very good fit of which is given by a Pareto distribution truncated at 1:

$$\Pr(NS \leq x) = 1 - x^{-k} \tag{1}$$

where NS is the number of HCRs affiliated with an institution and k is a parameter. The index k for the distribution of HCRs across institutions is equal to 1.21, a value that does not differ much from that obtained for income and city size distributions. Recall that the variance of a Pareto distribution tends to infinity once its index does not exceed 2, thus providing some first insights about the unevenness of the distribution of HCRs across institutions.[4] This observation seems to be confirmed by the fact that the median of the HCR-distribution is one, which means that the majority of institutions appearing in the data set has a single HCR. At the other extreme of the distribution, we observe that the top 25 institutions (listed in Table 2) account for 30.1% of the whole panel of HCRs and the top 50 for 43.3%.

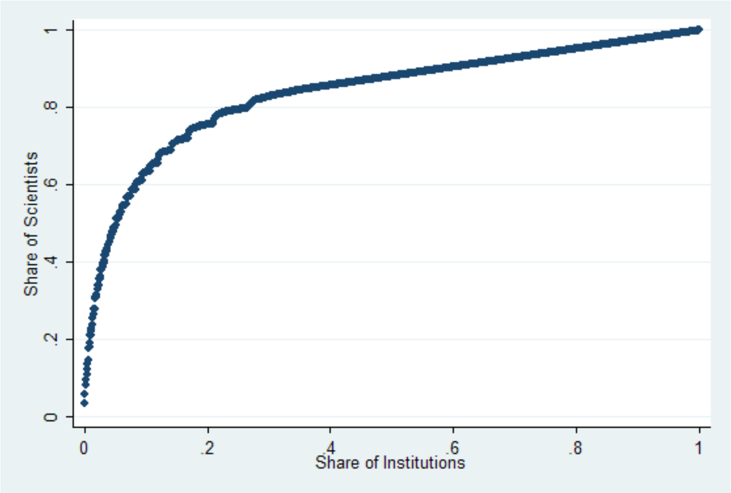

Figure 1: Cumulative distribution of the number of highly cited researchers per institution

Taking the reverse perspective, we observe that one third of the HCRs are affiliated with 30 institutions only. Out of these ones, there are 27 universities and three non-university research institutions, i.e. the National Institutes of Health (NIH), the Max Planck Institute (Germany) and the National Aeronautics and Space Administration (NASA). The NIH is an agency of the United States Department of Health and Human Services and is the primary agency of the American federal government responsible for biomedical research. The Max-Planck-Gesellschaft operates 80 research institutes all over Germany, which usually bear the name “Max Planck Institute (MPI) of ...”. Finally, the NASA is an agency of the United States federal government, responsible for the nation’s public space program.

Computing the normalized Herfindhal index over the set of institutions leads us to qualify our statement about the unevenness of the distribution of HCRs per institutions. Denoting by x_i the

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[4] Note, however, that the inverse of the index of the Pareto distribution is the standard deviation of the logarithm of the Pareto variable. So this index retains some meaning as a measure of concentration: the lower the index of the Pareto distribution, the more uneven the distribution of data.

share of HCRs affiliated with institution i, the Herfindhal index is given by

$$H = \sum\nolimits_{i=1}^{N} x_i^2$$

where N is the number of institutions. In order to control for this number, we use the normalized index defined by

$$H^* = \frac{H - 1/N}{1 - 1/N}$$

which varies within the range $[0, 1]$: the higher H^*, the more concentrated the distribution of data. Applying this index to the set of institutions, we find $H^* = 0.051$. This value is not as high as what the foregoing discussion would suggest. This may be explained by the fact that a large majority of institutions have a fairly small number of HCRs (recall that the median is one), as can be checked on the Web site ISIHighlyCited.com.

Looking now at the geographical breaking down, *the United States gets the lion's share with* 66% *of the total number of HCRs* (3829), while the EU17 (EU15 plus Norway and Switzerland) has 22.3% (1292).[5] It should be emphasized that the United Kingdom has 7.58% of the total number of HCRs (439), that is, slightly more than one third of the EU-share. In the top 25 institutions, 22 are located in the United States, two in the United Kingdom (Cambridge and Oxford) and one in Germany (the Max Planck Institute). In the top 50 institutions, 5 of them belong to the EU17 but only one is located in continental Europe, the Max Planck Institute. The second institution located in continental Europe (the ETH Zurich, Switzerland), is ranked 51*st*, the third (Karolinska Institutet, Sweden) 60*th*, the fourth (Leiden University, the Netherlands) 71*st*, and the fifth (Wageningen University, the Netherlands) 81*st*. In the 100 institutions with the largest numbers of HCRs, the EU accounts for only 15% while continental Europe gets a mere 7%. With such numbers in mind, we find it hard to think of European science as being in good shape.

Figure 2 gives the cumulative distribution of the number of HCRs per country. Again, a Pareto distribution truncated at 1 provides a good fit. However, its index is equal to 0.5, which is extremely low. In other words, *the distribution of HCRs per country is much more concentrated than the distribution per institutions.* This is confirmed by the value of the normalized Herfindhal index, which is now given by $H^* = 0.4357$. This is much higher than the value obtained for the institutions, a result that reflects the dominance of the American institutions as a whole.

Table 1 gives the list of disciplines selected by Thomson Scientific together with the numbers of HCRs per disciplines for the US and the EU17 with and without the UK. First of all, note

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[5] The 12 other members states of the EU 27 have only 7 HCRs all together.

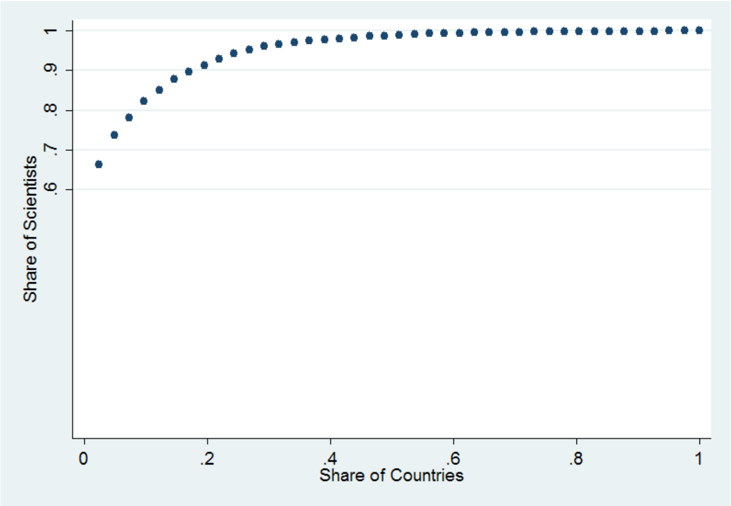

Figure 2: Cumulative distribution of the number of highly cited researchers per country

that Thomson Scientific has chosen to privilege the "hard sciences" at the expense of the others as only 2 out 21 disciplines belong to what we may call social sciences broadly defined. Yet, such an imbalanced breaking down into disciplines is not critical for our main point as most governments and international institutions care more about progresses in hard sciences for boosting economic growth. Second, it appears that the EU17 outstrips the US in a single discipline, i.e. *pharmacology*. The American institutions dominate in all the others. Note, in passing, the very poor performance of European economists, a result which may come as a surprise since English has become the lingua franca of the scientific economics and business community.

Table 1 also provides a few aggregate statistics that common wisdom would relate to research performance. The EU17 has a larger population but a lower per capita GDP in purchasing power parity. However, the total GDPs over the period 1980-2000 are rather close. The US remarkably outperforms the EU17 in both total R&D expenditure and average years of schooling of population aged 25 and over. Nevertheless, the above-mentioned differences in the numbers of HCRs are so high that it is hard to believe that these variables are sufficient to explain the stark contrast of research performances.

It should be emphasized that the comparison between the US and the EU17 hides very strong disparities within the European Union. Table 3 provides the number of HCRs per million inhabitants. Switzerland does almost as well as the US, while Israel is not far from the top two countries. The performance of three "small" European countries, i.e. Sweden, the Netherlands and Denmark, is also worth pointing out. With a much smaller population and a native language that is not

English, they outperform large European countries like Germany, France and Italy, or even Japan. Five English speaking-countries belong to the top-10, and it is fair to say that English is mastered by the large majority of the population in Sweden, the Netherlands and Denmark. As far as its scientific community is concerned, it is hard to think of Israel as being an outlier. The last member of the top-10, Switzerland, is a multilingual country in which English is not one of the four official languages.

Even though comparisons between institutions and countries may seem odd, it is worth stressing the fact that Harvard, which ranks first among institutions, has more HCRs than France, that the second and third American universities (Stanford and Berkeley) together have more HCRs than Germany, while the fourth American university (MIT) has more HCRs than Italy. Such performances for three of the largest and richest EU-countries are shocking. To say the least, they suggest that the university system of these three countries works pretty poorly in terms of scientific research.

Table 4 highlights the specialization of the country-members of the G7 with a focus on their top 4 disciplines. Results probably agree with what we know about the visibility of these countries in some disciplines. The fact that the US dominate most in social sciences and economics/business is the mirror image of the bad results obtained by European universities in these two disciplines. They are the two disciplines where literacy matters the most. Thus, it is tempting to conclude that the US dominance drives the good performance of English-speaking countries. This might well be true, but this explanation does not seem to hold for the United Kingdom. Indeed, Table 5 shows that the US and the UK are specialized in very different fields. More precisely, the rank-correlation between all disciplines in these two countries is equal to -0.44, thus suggesting that knowledge spillovers from one country to the other are not as strong as what is generally believed.

3 Why is it so bad in Europe?

In view of the facts summarized in the foregoing, a natural question comes to mind: what factors might explain the tremendous heterogeneity of our measure of scientific performance of countries? This section aims at providing an answer to this puzzle.

We can think of the scientific output as resulting from the interaction of several types of inputs such as the quantity and quality of physical inputs (buildings, equipment, computers, libraries...) and of human inputs (number of researchers and support staff, their level of education and experience). Measuring the stock of these inputs precisely is very difficult, not to say impossible, at least for many countries and long time periods. We must, therefore, resort to approximations. For material inputs, we use in reported estimations the research and expenditure outlays, denoted by RD_c for country c, in 2000. This is clearly a flow measure, but we find it reasonable to assume that this measure is more or less the same fraction of the corresponding stock in every country. In this respect, our supplementary data on the research and expenditure outlays of OECD and some partner-countries over the period 1981-2000 suggests that R&D expenditure differences across countries are strong but very stable across time. We have used this alternative measure for robustness tests. Furthermore, we choose the year 2000 because it is the closest one to the period of analysis (1981-1999) for which the data coverage is best. Regarding human inputs, we follow the literature on economic growth and approximate the stock of human capital in country c (HC_c) by the population size times the average number of years of schooling in 1980 (Benhabib and Spiegel, 1994; Barro and Sala-i-Martin, 1995). This year is selected because those who completed their education after 1980 are unlikely to be parts of the HCRs.[6]

We assume a Cobb-Douglas production function relating the number of HCRs in country c over the 1981-1999 period (NS_c) to the above inputs:

$$NS_c = \varphi_c \; RD_c^{\alpha} \; HC_c^{\beta} \tag{2}$$

where α and β are parameters to be estimated, and φ_c is a factor augmenting Hicks-neutral productivity term for country c. This factor is assumed to take the following form:

$$\varphi_c = (PCGDP_c)^{\gamma} \; e^{\theta_0 + \theta_1 Col\_UK_c} \; (Engl\_profic_c)^{\theta_2} \tag{3}$$

where (i) γ, θ_0, θ_1, and θ_2 are parameters to be estimated, (ii) $PCGDP_c$ is the average per capita GDP in purchasing power parity of country c over the period 1980-2000, (iii) Col_UK_c is a dummy indicating whether a country has been a UK colony with substantial participation in its own governance during the colonial period (UK is also included), and (iv) $Engl\_profic_c$ stands for a country's proficiency in English as measured by TOEFL test average scores by country of origin (see the data Appendix for details). The dummy Col_UK_c aims at capturing the idea that universities in English-speaking countries have specificities related to the design and governance of universities that make them more performant, while English proficiency accounts for the fact that English is the dominant language of scientific communication. As a matter of fact, HCRs publish

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[6] Details and sources of data are reported in the Appendix.

predominantly in English.[7]

It is standard in the growth and trade literature to consider per capita GDP in purchasing power parity as a proxy of a country's overall productivity (Barro and Sala-i-Martin, 1995; Trefler, 1995). Restricting ourselves to this single variable would amount to assuming that productivity differences in the research sector mirror those in the rest of the economy. Yet, we expect other variables to influence research productivity. This is why we include Col_UK_c since the UK and several of its former colonies seem to perform better than other countries (see Section 1). In an attempt to disentangle differences in the quality of institutions from the advantage of having a good English proficiency, we also introduce the variable $Engl\_profic_c$ in φ_c. Furthermore, in order to reduce the possible impact of proficiency in English, we consider the hard sciences only to build NS_c; i.e. we neglect those HCRs belonging to the "Economics-Business" and "Social Sciences, General" disciplines where literacy matters the most.

Since NS_c is a count variable, we estimate we estimate a Poisson model by quasi-maximum likelihood (QML). Specifically, we proceed as if NS_c were to follow a Poisson distribution with conditional mean equal to $\exp(\theta_0 + \theta_1 Col\_UK_c)\ (PCGDP_c)^{\gamma}\ (Engl\_profic_c)^{\theta_2}\ RD_c^{\alpha}\ HC_c^{\beta}$ and observations were independent. It should be clear that the parameters γ, θ_2, α, and β have the nature of elasticities. The foregoing assumptions determine the likelihood function of the observed sample, which we maximize to obtain QML estimates of the parameters in (2) and (3). Note that the QML method yields consistent estimates even though the true distribution of counts is not of the Poisson-type, provided that the conditional mean is correctly specified. In addition, we use robust standard errors for statistical inference.[8]

Our sample consists of 65 countries (see Table 6). It includes 38 of the 41 countries having at least one HCR (Algeria, Iran, and Taiwan are lost due to data availability) and 27 other countries that have a count of 0. The selection of these additional 27 countries was based on data availability. However, our results are not significantly affected by the introduction of such countries, thus suggesting that there is no strong selection bias in our analysis.

Several estimation results are reported in Table 7. In columns (1) and (2), in which neither the former UK colony dummy nor the English proficiency variable are included, the model performs

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[7] We have checked that from the publications of HCRs who do not not belong to English speaking countries using a random sample of 10% of them extracted from the Thomson Scientific on-line database. In a few countries, such as Germany, Italy and France, HCRs have a small fraction of their publications in their native language. We have found a single case (a German psychiatrist) in which the publication record was approximately half in English and half in German. In all other cases, the most cited papers are written in English.

[8] See e.g. Wooldridge (2002), section 19.2.2.

pretty badly in that $PCGDP_c$ is the only significant variable besides the constant term, while the estimates are very sensitive to the exclusion of the US from the estimation sample. In other words, neglecting English proficiency and the UK legacy implies that R&D outlays and human capital are not relevant for the production of HCRs, and makes the US a big outlier whose weight changes completely point estimates. By contrast, *including* Col_UK *and* $Engl\_profic$ *renders the estimates stable with respect to the exclusion of the US* (compare columns (3) and (4)), *while improving parameter significance*. Furthermore, the estimates of model (3) provides some evidence in favor of mildly decreasing returns to scale, the p-value for the null hypothesis that $\alpha + \beta = 1$ being below 5%.

One could argue that endogeneity is a likely issue in the foregoing estimations. While no one would deny that per capita GDP has an impact on the scientific output, one could similarly argue, as in modern growth theories, that there is a feedback effect in that a higher scientific output favors economic growth. In this case, per capita GDP cannot be treated as being exogenous in the estimation of the model parameters. Nevertheless, one may be tempted to say that the knowledge contained in scientific publications is a public good that is freely available to the world's scientific community. We believe, however, that HCRs contribute disproportionately to the GDP of their host country for at least two reasons. The first one is that part of the knowledge produced by HCRs flows across space and time with frictions, thus providing a local advantage for a while (Jaffe et al., 1993; Peri, 2005). The second one is that HCRs have other activities that may have a direct impact on the national or local GDP, such as consulting activities for local firms and governments on a very large scale as in the US.

In column (5), our preferred specification, we report the estimates when we instrument $PCGDP$ by the per capita GDP in 1913 (few countries are lost because of the lack of 1913 data). By instrumenting, we mean that PCGDP (in level) is replaced by its predicted value estimated from a linear projection of the log of PCGDP on the log of per capita GDP in 1913, the log of RD, the log of HC, the UK colony dummy and the log of the proficiency variable. There are two conditions for the log of per capita GDP in 1913 to be a valid instrument for the endogenous variable: it must be uncorrelated with the error term of the production function (a non-testable assumption) and it must be correlated with the log of PCGDP (the endogenous variable). The last condition is clearly satisfied since the t-statistic for the coefficient of the log of per capita GDP in 1913 is equal to 7.97 in the linear projection. The non-testable assumption can be justified by saying that it is unlikely that the level of GDP in 1913 has been determined by the non-observable factors that determined

GDP in 1980 and after (Ciccone and Hall, 1996). Moreover, the presence of structural breaks should provide the condition for a natural experiment. In this respect, almost 70 years separate the two periods, with two world wars in-between, a strong modification in the composition of GDPs from agriculture to services through industry, the Great Depression and the after-war process of economic integration, which all seem to have the nature of structural breaks.

Taking care of the endogeneity problem, the coefficient of per capita GDP increases considerably from 1.54 in column (3) to 1.94 in column (5). The other parameter estimates are somewhat different from those provided in column (3), but the coefficient of HC becomes significant. The quality of the fit is high since the correlation between actual and predicted numbers of HCRs is equal to 0.99 (the square root of the pseudo-R^2 given in Table 7). In unreported results, we also found that excluding the US does not change the estimates. Overall, the changes in estimates reveal that the endogeneity problem encountered here is not related to the fact we use a restricted sample of countries.[9] As a robustness check, we have estimated the production function on the restricted sample of countries for which research and development spending was available for the entire period 1981-2000, using the reconstructed total R&D outlays over this period to get a better measure of the stock of physical inputs for HCRs production. These unreported results confirm our previous findings.

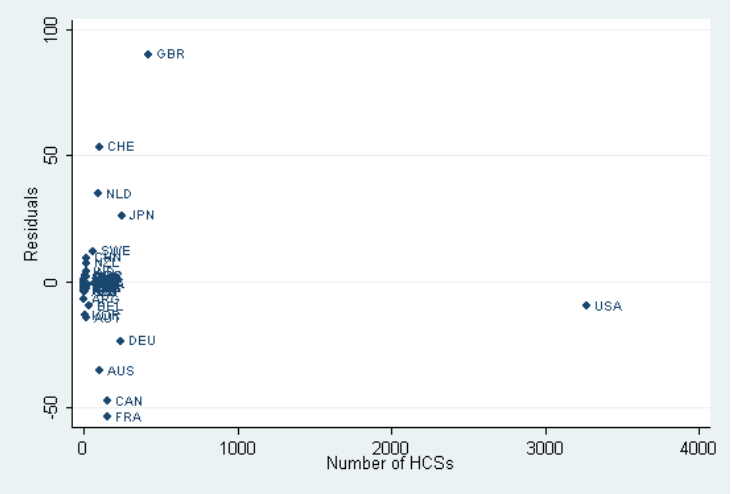

Figure 3: Residuals of the estimated production function (see column (5) of Table 7)

Figure 3 displays the residuals resulting from the estimation of the model in column (5).[10]

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[9] We have also estimated (3) using the same sample as in (5) and have found almost the same results as in (3).

[10] The residuals are the differences between the observed number of researchers and their estimated value using the production function.

We see that the UK has a number of HCRs that exceeds considerably the predicted one. This discrepancy may reflect the strong research tradition of British universities as well as the fact that they have acquired a lot of autonomy in hiring, wage-setting and budget management, while research funds are allocated according to a very selective procedure (Aghion et al., 2007). At the other extreme of the spectrum, France has a number of actual HCRs that is much smaller than the predicted one. The fact that French universities are over-regulated will come to the mind of those who are familiar with them.

Using the estimates of column (5) in Table 7, we see that *the English proficiency effect is fairly strong*. For example, if France were to improve its English proficiency by 10%, thus reaching the level of the Netherlands, the number of French HCRs would increase in the long run by 25%. However, besides their linguistic advantage, *former UK colonies also display a higher efficiency in producing HCRs*. For example, Australia, Canada, Ireland, Israel, New Zealand, Singapore, the UK and the US have, ceteris paribus, 76% ($\exp(0.565) - 1$) more HCRs than other countries. In order to match such an advantage, EU countries should more than double their research budget, or more than triplicate their human capital stock, or increase their GDP by around 40%. These numbers give an idea of the strength of the UK legacy or, maybe, of the choice of US-like academic institutions made in those countries. In any case, they suggest that a variable directly related to *the quality of the design of academic institutions* matters more than the R&D budget, the GDP level and human capital in achieving top-level research performances.

We have used our model to simulate the implications of possible policies to be implemented in order to reach a much higher research output. First, if the EU17 were to achieve the Lisbon objective of a GDP-share in R&D equal to 3%, its share of HCRs would just slightly increase from 22.3% to 28.4%, while the US would still account for 59.7% of HCRs. This sheds new light on the possible ineffectiveness of the EU objective regarding European universities. Moreover, if the 3% objective was further accompanied by an increase of both the EU educational level and GDP per capita to their corresponding US counterparts, the EU17 share of HCRs (36.8%) would still be far behind the US share (52.6%). Hence, the EU must seek alternative solutions.

If the 3% objective were to be combined with a deep reform of the design and governance of EU research institutions that would bring them at the US level of efficiency, the EU share of HCRs would go up 37.7%, while the US share would be equal to 51.9%. In addition, if the level of English proficiency were to be raised to the level of the Netherlands in non-native English speaking EU17 countries, the gap between the EU and the US would almost vanish (41.2% for the EU vs. 49%

for the US). These last results suggest new policies to remedy the resistible decline of European science.

4 What to do?

Money matters in science as it often does in human affairs. Indisputably, a larger research budget would help the EU boost European science. However, money is not the only leverage for European universities to have a better research output.

In this paper, we have argued that the governance and design of research institutions and universities are critical inputs in knowledge production, a fact that European researchers and public decision makers tend to dismiss far too often. This covers a large number of issues, ranging from the ability of hiring new researchers to the linkage of professors' salary and promotion to their scientific (and teaching) output, through more flexibility in managing research funds and the development of research centers having a critical size. In this respect, we find it fair to say that the bureaucratic procedures implemented by the European Commission in allocating research funds are incredibly heavy and discouraging. We have also shown that English proficiency is another critical element. This should not come as a surprise as using a common language is the source of strong network externalities. To put it bluntly, graduate teaching and scientific publishing should be done in English, even in non English-speaking countries.

As said above, we would be the last to claim that university and research budgets do not matter in the performance of researchers (Aghion et al., 2007). However, it is worth stressing that, to a large extent, those budgets are themselves endogenous: outstanding universities attract big flows of money precisely because they are outstanding, and vice versa. We encounter here the well-known phenomenon of "cumulative causation" developed by Myrdal (1957) fifty years ago, which has, since then, been successfully applied to many economic fields (Matsuyama, 1995). Besides this observation, our analysis suggests that *the way the money is used is probably as critical as the amount of money itself.*

At a time when the opportunity cost of public funds is likely to rise sharply, this is not necessarily bad news. The scientific community should become fully aware of the main weaknesses of research institutions in many countries of continental Europe. By promoting in-depth reforms, national governments and the European Commission would vastly contribute to the "irresistible" growth of their universities in the production of advanced and successful knowledge. Designing better research institutions, which does not necessarily mean copying Anglo-Saxon universities, and learning better

English need not much money. It requires, however, more openness to the rest of the world on the part of quite a few European researchers, as well as collective imagination and political will. The key question thus becomes: does Europe have them?

Appendix

- Historical R&D data for OECD and some partner countries comes from the *OECD Main Science and Technology Indicators.*
- Data on R&D in 2000 for a larger set of countries comes from the Science and Technology database provided by the UNESCO Institute of Statistics.
- Data on colonial ties comes from CEPII at http://www.cepii.fr/anglaisgraph/bdd/TradeProd.htm.
- Data on Population and GDP per capita in purchasing power parity comes from the World Economic Outlook Database, April 2007 provided by International Monetary Fund.
- Data on GDP for 1913 is provided by Maddison, A. (2001) *The World Economy. A Millennial Perspective.* Paris OECD.
- Data on Average Years of Schooling for total population aged 25 and over comes from Robert J. Barro and Jong-Wha Lee (2001) International data on educational attainment: updates and implications. *Oxford Economic Papers* 53, 541-563. Data are available at http://www.cid.harvard.edu/ciddata/ciddata.html.
- Data on TOEFL average scores of computer-based tests by country of origin for the examination period July 2004 to June 2005 comes from *TOEFL Test and Score Data: Summary Data.* TOEFL data for the UK, US, Canada, New Zealand, Australia and Ireland were not available because English is the native language in those countries and so there is no need to prove English proficiency with a test. TOEFL scores have thus been reconstructed by regressing TOEFL scores for available countries on data about the share of English-speaking population and average years of schooling in a given country. The imputed TOEFL scores are: Australia (266), Canada (264), Ireland (267), New Zealand (270), United Kingdom (268), United States (268). As a comparison, countries with the best English proficiency, like Denmark and the Netherlands, score around 260. Good English proficiency countries like Germany and Switzerland score around 250, while medium performance countries like France

and Spain score around 240. We have used other values of the TOEFL test for the above 6 missing countries. As long as scores are below 285, the Col_UK dummy is still positive and significant. The maximum achievable score of the test is 300.

- The data on countries and their English-speaking population comes from different sources collected by Wikipedia at http://en.wikipedia.org/wiki/List_of_countries_by_English-speaking_population). In particular, for EU countries, data comes from a survey whose results are published in the *Special Eurobarometer 243* (2006). See http://ec.europa.eu/public_opinion/archives/ebs/ebs_243_en.pdf.

Table 1: Number of highly cited researchers by discipline in the US, EU17 (EU15 plus Norway and Switzerland) and EU17 without the UK

Discipline	US	EU17	EU17 without UK
Agricultural Sciences	113	84	64
Biology and Biochemistry	138	40	29
Chemistry	143	72	51
Clinical Medicine	161	36	17
Computer Science	226	45	35
Ecology-Environment	192	73	48
Economics-Business	263	24	11
Engineering	138	32	24
Geosciences	219	70	43
Immunology	201	81	66
Materials Science	159	50	33
Mathematics	221	75	53
Microbiology	159	71	49
Molecular Biology and Genetics	197	63	47
Neuroscience	182	73	39
Pharmacology	93	121	73
Physics	148	74	59
Plant and Animal Science	147	100	59
Psychology-Psychiatry	228	23	5
Social Sciences, General	295	11	3
Space Sciences	206	74	45
Total	3829	1292	853
Aggregate economic indicators			
Total GDP-PPP, average 1980-2000	5.81E+12	6.5E+12	5.48E+12
Population 1980	227.62	363.87	307.54
Per capita GDP-PPP, average 1980-2000	22,786	17,252	17,170
R&D expenditure, total in 2000	2.64E+11	1.81E+11	1.54E+11
R&D expenditure as % share of GDP in 2000	2.74	1.88	1.88
Average years of schooling in 1980	11.91	7.38	7.23

The average of total GDP in purchasing power parity (PPP) over the period 1980-2000 is measured in current US dollars. The same unit is used for both average per capita GDP in PPP over the period 1980-2000 and total R&D Expenditure in the year 2000. Population is measured in million number of inhabitants.

Table 2: Top 25 institutions by number of highly cited researchers

Institution	Number of HCRs	Country
Harvard University	180	United States
National Institutes of Health	136	United States
Stanford University	135	United States
University of California, Berkeley	83	United States
Massachusetts Institute of Technology	78	United States
Max Planck Institute	69	Germany
University of Michigan	68	United States
Princeton University	64	United States
California Institute of Technology	61	United States
University of California, San Diego	61	United States
Yale University	61	United States
University of Pennsylvania	59	United States
Columbia University	58	United States
University of California, Los Angeles	58	United States
Cornell University	55	United States
University of California, San Francisco	53	United States
University of Wisconsin - Madison	51	United States
University of Cambridge	50	United Kingdom
University of Washington	50	United States
University of Chicago	47	United States
NASA	43	United States
University of Minnesota	43	United States
Duke University	40	United States
Northwestern University	40	United States
University of Oxford	40	United Kingdom

Table 3: Top 20 countries by number of highly cited researchers per million inhabitants

Country	HCRs per mill. inhabitants	Number of HCRs
United States	16.82	3829
Switzerland	16.28	103
Israel	12.49	47
United Kingdom	7.79	439
Australia	7.13	105
Sweden	7.09	59
Canada	7.03	172
Netherlands	6.50	92
Denmark	5.47	28
New Zealand	5.46	17
Belgium	3.55	35
Finland	3.14	15
Germany	3.12	240
Norway	2.93	12
France	2.88	155
Japan	2.12	247
Ireland	2.06	7
Singapore	1.66	4
Austria	1.59	12
Italy	1.28	72
EU17	3.55	1292

Table 4: Top 4 disciplines by percentage of highly cited researchers for the G7 countries.

Country	1st Discipline	2nd Discipline	3rd Discipline	4th Discipline
US	Social Sciences, General	Economics-Business	Psychology-Psychiatry	Clinical Medicine
% HCRs	93.06	86.51	86.04	77.03
Japan	Biology & Biochemistry	Materials Science	Agricultural Sciences	Physics
% HCRs	13.18	11.92	11.15	8.95
Germany	Chemistry	Plant & Animal Science	Physics	Pharmacology
% HCRs	10.40	8.25	8.17	7.66
France	Mathematics	Geosciences	Agricultural Sciences	Immunology
% HCRs	6.77	6.71	5.20	4.43
UK	Pharmacology	Plant & Animal Science	Neuroscience	Space Sciences
% HCRs	18.39	13.53	12.27	9.24
Italy	Pharmacology	Space Sciences	Immunology	Physics
% HCRs	4.21	3.50	3.16	2.72
Canada	Plant & Animal Science	Agricultural Sciences	Ecology-Environment	Engineering
% HCRs	6.60	6.32	4.71	4.52

Table 5: Ranking of the UK and the US in the 21 disciplines according to percentage of highly cited researchers

UK		US	
Ranking	Discipline	Ranking	Discipline
1	Pharmacology	1	Social Sciences, General
2	Plant & Animal Science	2	Economics/Business
3	Neuroscience	3	Psychology/Psychiatry
4	Space Sciences	4	Clinical Medicine
5	Clinical Medicine	5	Computer Science
6	Microbiology	6	Molecular Biology & Genetics
7	Geosciences	7	Geosciences
8	Ecology/Environment	8	Engineering
9	Chemistry	9	Mathematics
10	Agricultural Sciences	10	Neuroscience
11	Psychology/Psychiatry	11	Space Sciences
12	Mathematics	12	Ecology/Environment
13	Materials Science	13	Microbiology
14	Physics	14	Immunology
15	Molecular Biology & Genetics	15	Biology & Biochemistry
16	Biology & Biochemistry	16	Materials Science
17	Immunology	17	Physics
18	Economics/Business	18	Chemistry
19	Engineering	19	Plant & Animal Science
20	Computer Science	20	Agricultural Sciences
21	Social Sciences, General	21	Pharmacology

Table 6: List of countries included in the analysis

Country	Number of HCRs	Col_UK
Argentina	0	NO
Australia	105	YES
Austria	12	NO
Belgium	35	NO
Bulgaria	0	NO
Bolivia	0	NO
Brazil	4	NO
Canada	172	YES
Switzerland	103	NO
Chile	3	NO
China	19	NO
Colombia	0	NO
Costa Rica	0	NO
Cyprus	0	YES
Germany	240	NO
Denmark	28	NO
Ecuador	0	NO
Egypt	0	YES
Spain	18	NO
Finland	15	NO
France	155	NO
United Kingdom	439	YES
Greece	4	NO
Hong Kong SAR	0	YES
Honduras	0	NO
Hungary	4	NO
Indonesia	0	NO
India	11	YES
Ireland	7	YES
Iceland	0	NO
Israel	47	YES
Italy	72	NO
Jamaica	0	YES
Japan	247	NO
Korea (Republic of)	3	NO
Kuwait	0	YES
Sri Lanka	0	YES
Mexico	3	NO
Malta	0	YES
Mauritius	0	YES
Malaysia	0	YES
Netherlands	92	NO
Norway	12	NO
New Zealand	17	YES
Pakistan	1	YES
Panama	1	NO
Peru	0	NO
Philippines	1	NO
Poland	2	NO
Portugal	1	NO
Paraguay	0	NO
Romania	1	NO
Sudan	0	YES
Singapore	4	YES
Sweden	59	NO
Thailand	0	NO
Tunisia	0	NO
Turkey	1	NO
Uganda	0	YES
Uruguay	0	NO
United States	3829	YES
Venezuela	0	NO
Former USSR	5	NO
Czechoslovakia	0	NO
South Africa	7	YES

Table 7: Poisson QML estimation results for the knowledge production function

Regressors (parameters)	(1)	(2)	(3)	(4)	(5) IV
constant (θ_0)	-33.721***	-25.0383***	-38.761***	-42.801***	-39.147***
	(7.576)	(5.018)	(3.619)	(4.694)	(3.693)
RD (α)	0.081	0.397	0.780***	0.863***	0.648***
	(0.669)	(0.379)	(0.196)	(0.203)	(0.162)
HC (β)	0.942	0.395	0.118	0.115	0.343**
	(0.650)	(0.407)	(0.173)	(0.172)	(0.175)
PCGDP (γ)	3.262**	2.137***	1.543***	1.566***	1.939***
	(1.439)	(0.832)	(0.480)	(0.516)	(0.278)
Col_UK (θ_1)			0.577***	0.631***	0.565***
			(0.153)	(0.188)	(0.171)
Engl_profic (θ_2)			2.638***	3.082***	2.181***
			(0.477)	(0.664)	(0.549)
Pseudo R^2	0.956	0.841	0.981	0.922	0.984
Wald test for $\alpha + \beta = 1$	0.10	3.49	4.23	0.07	0.04
p-value for Wald test	0.754	0.061	0.040	0.790	0.844
Sample restrictions	None	No US	None	No US	Available GDP 1913
Number of countries	65	64	65	64	53
Instrumented variable	None	None	None	None	*PCGDP*

The model is defined by equations (1) and (2) in the text. Dependent variable: Number of HCRs by country in all disciplines but Economics-Business and Social Sciences, General. QML standard errors in parentheses with ***, ** and * respectively denoting significance at the 1%, 5% and 10% levels.

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