

Making the most of world talent for science? The Nobel Prize and Fields Medal experience

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Received: 16 January 2021 / Accepted: 26 November 2021 © The Author(s) 2021

Abstract

Opportunities in science largely affect the accumulation of scientific knowledge and, therefore, technological change. However, there is little evidence of how much of people's talent is actually wasted. Here we focus on scientists with the highest performance, the recipients of the Nobel Prize and Fields Medal. We found that the average age of scientists at the time of the breakthrough was higher for researchers from less developed countries. Moreover, individual opportunities in the world were extremely unequal by country of birth, gender significantly conditioned any participation in research, and the probability of becoming a top researcher more than doubled for individuals with parents belonging to the most favoured occupational categories. Thus, inequality of opportunity in science at the highest level was higher than in sports excellence (Olympic medals) and educational attainment. These findings would not be so negative if opportunities in science at the highest level had increased over time. Contrary to the expectations, our results show that opportunities in science, in contrast with humanities, have stagnated.

Keywords Individual opportunities · Science · Humanities · Nobel Prize · Fields Medal

I am, somehow, less interested in the weight and convolutions of Einstein's brain than in the near certainty that people of equal talent have lived and died in cotton fields and sweatshops

(Stephen Jay Gould, 1980)

Introduction

The basic idea behind the scientific method is the belief in contestability and the commitment to open science. However, these goals can be fully achieved only if there are no barriers to research careers because ideas require individuals with good brains regardless of their birthplace, gender or socioeconomic origin. Unfortunately, even if individuals have

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great inborn talent, the likelihood of their being able to realize the benefits of that talent may be affected by social conditions (Bowles et al., 2005).¹ Notice that significant individual opportunities in science make the most of people's talent to promote not only the scientific quest, but also economic development since long-run economic growth arises fundamentally from people that create new ideas.² Technological change is the main source of sustained economic growth and, despite that technology increased without any significant development in science until the first Industrial Revolution, science has been the dominant driving force ever since then (Mokyr, 2017). Consequently, we ask here whether individual opportunities in science have been sufficiently large not to deter the scientific progress and, therefore, economic growth.

The answer to this question is even more important when ideas become harder to find over time (instead of being prompted by previous scientific knowledge), because to maintain the pace of scientific progress, the diminishing returns of the production of ideas (Bloom et al., 2017; Griliches, 1994; Jones, 2009) have to be offset by an increasing number and quality of scientists. To obtain evidence regarding how large were opportunities to be a top-class scientist in the world, we study the recipients of the Nobel Prize (1901–2020) and Fields Medal awards (1936–2018).

Low individual opportunities for science not only may keep people's talent out of research, but also may significantly influence the age at the time of the breakthrough. Individual circumstances like the country of birth, socioeconomic background and gender may condition the access to high quality education and, more in general, the process of learning which in turn can affect the age at the time of the main discovery. Therefore, it is also useful to ask which personal traits help to reduce the age at the time of the breakthrough.

In addition, we know that scientific knowledge is cumulative since new ideas build on previous discoveries.³ As a result, existing ideas may induce more knowledge (the combinatory theory of ideas) or, on the contrary, may make harder to find new ideas. Under the second scenario, more and better education, more sophisticated labs and installations, and stronger collaboration between scientists become essential to maintain the pace of technological change. However, these requirements are considerably costly so more and more individuals (and countries) could be progressively left behind. If so, a very valuable but scarce resource, human talent, could be less efficiently allocated over time. Does the production of ideas become harder over time? And if so, is this process linear or exponential?

Elucidating these questions is important because significant opportunities in science make the most of people's talent to promote knowledge, technological change and economic growth. At the same time, this knowledge-driven economic growth incentives economies to invest more in education and research which creates, in principle, more individual opportunities for science. Then, more individual opportunities in science may increase technological progress and, simultaneously, technological change may generate

¹ For example, one key factor for science, educational attainment, has been found to be primarily determined by social and other environmental factors. Thus, studies using the Genome-wide Complex Trait Analysis provide an estimate of 'only' 22% for the heritability of years in education and 25% for attending college (Rietveld et al., 2013).

² Once produced, ideas fuel sustained growth in ways that are not possible for other factors of production because they are non-rivalrous, i.e., ideas can be copied and shared with minimal costs (Aghion & Howitt, 1992; Grossman & Helpman, 1991; Jones, 1995; Kortum, 1997; Romer, 1990).

³ Recall the motto attributed to Bernard of Chartres, 'Nanos gigantum humeris insidentes', which was popularized later by Newton, 'If I have seen further, it is by standing on the shoulders of giants'.

more opportunities for research.⁴ Given this potential virtuous circle between opportunities and technological change, have individual opportunities in science at the highest level increased over time?

To study all these issues, we provide a worldwide view of individual opportunities in science from the beginning of the twentieth century by focusing on scientists with the best performance. We use the recipients of the Nobel Prize (1901–2020) to analyse opportunities in science at the highest level since 1901. In addition to the awards in science (physics, chemistry and medicine), we consider the awards in humanities (literature and peace) as control group. For robustness, we also analyse the Nobel Prize in economics (1969–2020) and the Fields Medal awards (1936–2018) in mathematics.

We found an exponential increase in the average age of scientists at the time of the breakthrough and bad individual circumstances significantly delayed the breakthrough. In particular, the age at breakthrough was found to be negatively related to the average level of education (enrolment rate in tertiary education) and health (life expectancy) in the researcher's country of birth. Consequently, the average age of scientists at the time of the breakthrough was higher for researchers from less developed countries.

Despite the significant increase in the geographical mobility of researchers throughout the twentieth century, individual opportunities in science by country of birth were found to be extremely unequal. In fact, becoming a top-class scientist in the world (by country of birth) was found to be harder than becoming an Olympic medalist. Gender was found to be an individual trait that can also condition the participation in science in a fundamental way. In addition, the socioeconomic background of individuals was also important for science. The probability of doing scientific research at the highest level of an individual with parents belonging to the most favoured occupational categories more than doubled the probability of an individual with parents belonging to the least favoured occupational categories.

These findings would not be so negative if individual opportunities in science had increased over time. Contrary to expectations, our estimates showed that opportunities for science, in contrast with humanities, have suffered from stagnation. The requirements needed to maintain the pace of innovation (more and better education, more sophisticated labs, bigger installations and greater number of collaborations) have created many opportunities for research but have also left behind many individuals with bad initial circumstances due to their large costs. The large barriers existing in science at the highest level, it seems, have not been reduced sufficiently not to harm innovation and growth.

The rest of the paper is structured as follows. In Sect. 2, we present the Nobel Prize (1901–2020) and Fields Medal (1936–2018) databases, describing their construction and main characteristics. In Sect. 3, we estimate the change in the average age of scientists at the time of the breakthrough and how individual circumstances affect the discovery of new ideas. Section 3 presents the distribution of individual opportunities in science at the highest level by individual circumstances. In Sect. 5, we show the evolution of individual opportunities in science at the highest level over time. Finally, Sect. 6 discusses the main results.

⁴ For example, the invention of the pill significantly enlarged the career opportunities of women (Goldin & Katz, 2002).

The Nobel Prize (1901–2020) and Fields Medal (1936–2018) databases

This work is based on two databases, i.e., the Nobel Prize database (1901–2020) and the Fields Medal database (1936–2018). Because we are interested in science (n = 624), we focus on the Nobel Prize winners in physics (n = 216), chemistry (n = 186) and medicine (n = 222). For the sake of comparison ('control group'), we also consider the awards in literature (n = 117) and peace (n = 135). Accordingly, throughout the paper, science denotes the awards in physics, chemistry and medicine, while *humanities* include the awards in literature and peace. We should recall that the Nobel Prize is an annual award which was first introduced in 1901 and that 28 Nobel Peace Prizes have been awarded to international organizations and therefore we have not used them. For the sake of robustness, we also use the Nobel Prize winners in economics (n = 86) and the Fields Medal awards in mathematics. Because economics is a social science not a natural science that was not awarded with the Nobel Prize until 1969 and the Fields Medal prize which has been given from 1936 to 2018 every four years has only been awarded on a regular basis since 1950 (n = 60), has a maximum age to be granted (40 years old) and its maximum number of recipients is 4 (instead of 3), we prefer not to include these awards in the pool of science and to use them as an additional robustness analysis.

The bulk of these two databases derives from the information provided by the official websites of the Nobel Foundation (http://www.nobelprize.org/) and the International Mathematical Union (http://www.mathunion.org/general/prizes/fields/prizewinners/). However, given the difficulties to find information about parental occupation and the exact date of the main discovery, we have also consulted the information available in many other sources.⁵

The main variables collected from these databases are the following: the date and country of birth, the country of the alma mater, the country of residence in the year of the award, the highest educational degree, gender, the age at the time of the award, the age at the time of the main breakthrough, and parental occupation. In addition to these variables, we use the country population in 2015 (United Nations, 2017), and the real GDP per capita (Bolt et al., 2018), the enrolment ratio in tertiary education (Lee & Lee, 2016) and the life expectancy (Roser et al., 2020) of the researcher's country at the year of birth.

In principle, the age of the Nobel Prize winners in science and economics and the Fields Medal winners at the time of their main breakthrough according to the Nobel and Fields Medal Committees is considered for all researchers. The values used in the paper refer to the year of the main contribution, although many discoveries cannot be attributed to a single year. For this reason, we take the middle year of the interval between the early and late dates of achievement. Nonetheless, many Nobel Prize winners made multiple subcontributions over large periods of time. For example, the interval of multiple subcontributions for

⁵ These data sources are the following: the Royal Society (http://rsbm.royalsocietypublishing.org/); the National Academy of Sciences (http://www.nasonline.org/publications/biographical-memoirs/); the National Academies Press (https://www.nap.edu); the Encyclopaedia Britannica (http://www.britannica. com/); the MacTutor History of Mathematics archive (http://www-history.mcs.st-and.ac.uk/Societies/ FieldsMedal.html); Wikipedia (www.wikipedia.org); the American Physical Society (http://www.aps. org/); Famous Scientists (https://www.famousscientists.org); the American Association of Immunologists (http://aai.org/about/history/Notable_Members/Nobel/index.html); the Academy of Achievement (http:// www.achievement.org/); Encyclopedia.com (http://www.encyclopedia.com/); Google Books (https://books. google.com/); Internet Archive (https://ebook.worldlibrary.net); the Literary Encyclopaedia (http://www.mayoclinic proceedings.org); and some other sources cited in the database.

62 Nobel Prize winners in science was 9 years or more. This fact could significantly diminish the degree of accuracy of our estimations. Accordingly, we replicate the analysis of this variable in Sect. 3 for those researchers whose main writings were published over a period of four years or less (n = 526 for science, n = 48 for economics and n = 40 for mathematics).⁶ In humanities, it seems that a large percentage of awards were for lifelong work given that for 95.7% of the awards in literature and 58.9% in peace, the main contribution was published or carried out over a period of five years or more.

The country of birth, the country of the alma mater and the country of residence in the year of the award refer to the current list of countries in the world. To measure geographical mobility, we compare the birthplace of the individual with his/her country of residence in the year of winning the award or with his/her alma mater country. If the country is the same, we assign 0, and 1 otherwise. Then, for clarity of exposition, we accumulate the values and normalise total mobility to 100%. When life expectancy is not available for a given country and year, weighted interpolation is applied (for periods no longer than 11 years). Finally, parental occupation refers to the highest occupation of the parents or any other close ancestor. Results are similar if father's occupation is considered instead. The considered occupational categories are the following: (1) Aristocrats, manufacturers and proprietors; (2) Managers, chief executives, heads of division, diplomats, deans, and generals; (3) Science and engineering professionals, college and high-school teaching professionals, businessmen, stockbrokers, high-rank clerical workers, and army officers; (4) Clerical support workers, services and sales workers, merchants, foremen, school teachers, and shopkeepers; (5) Craftsmen, farmers, musicians and clergymen; and (6) Elementary workers, agricultural, forestry, mining and construction labourers, and assistant workers.

To show our results of inequality of opportunities in science at the highest level we use the Lorenz curve (L) in Sect. 4 so that a formal definition of it is also necessary. Let $x = (x_1, x_2, ..., x_N)$ be an outcome distribution for a population of size N, where $x_i \ge 0$ is the outcome of person i. Typically, the outcome is income, wealth or earnings, in our case we use the probability that an individual has to become a top-class scientist in the world. For a fixed $N \ge 1$, the set of all outcome distributions is Γ^N , the nonnegative orthant of the N-dimensional Euclidean space \mathbb{R}^N with the origin deleted. Let D^N be that subset of Γ^N in which all outcome distributions are nondecreasingly ordered, i.e., for all $x \in D^N$, $x_1 \le x_2 \le \cdots \le x_N$. Then, for any given $x \in D^N$, its Lorenz curve

$$L_x\left(\frac{j}{N}\right) = \sum_{i=1}^{j} \frac{x_i}{X} \quad 1 \le j \le N \tag{1}$$

where $X = \sum_{i=1}^{j} x_i$ is total outcome, represents the share of the total outcome possessed by the cumulative $\frac{j}{N}$ proportion of the population. If all individuals have the same outcome, the resulting curve will be the 45-degree line, the line of equality. Otherwise, the resulting Lorenz curve will lie below the 45-degree line and will be bowed-inward (Lambert, 2001). In fact, the Lorenz curve will have more bend and will be closer to the bottom horizontal axis, if the degree of inequality is greater. For $x, y \in D$, x is said to Lorenz dominate y if $L_x(q) \ge L_y(q)$ for all $q \in [0, 1]$, and $L_x \ne L_y$. Note that the population sizes need not be the same (Chakravarty, 2009).

One alternative way to summarize the underlying degree of inequality is to measure the area between the Lorenz curve and the 45-degree line as a fraction of the total area under

⁶ The results are similar when other intervals of time (1, 2, 3 and 5 years) are considered.

the 45-degree line. This is the Gini coefficient (*G*), with higher Gini's representing higher degrees of inequality. The Gini coefficient lies somewhere between 0 and $\frac{N-1}{N}$. For large populations the upper bound $\frac{N-1}{N}$ converges to 1, but for small populations the Gini coefficient must be rescaled by $\frac{N}{N-1}$ to convert this coefficient to something between 0 and 1.

The age of scientists at the time of the breakthrough

We need more talent to maintain the pace of scientific progress (and economic growth) if the returns in the production of science either the elaboration or the validation of scientific ideas are diminishing (Bloom et al., 2017; Griliches, 1994; Jones, 2009). For this reason, it is important to elucidate whether old ideas facilitate the discovery of new ideas or, on the contrary, if the production of science becomes harder over time. For this task, we consider the age at the time of the breakthrough (measured by the time of the main publication). If increasingly more learning is required to push the frontier of knowledge forward, either more training or narrowing expertise will be needed which, in turn, makes the age at the time of the main discovery increase over time (Jones, 2010; Lehman, 1953; Simonton, 1991).

On the other hand, the age at the time of the main discovery might also be affected by individual circumstances like the place of birth, gender and parental occupation. If so, opportunities in science would have an influence on the age at the time of the breakthrough. As a result, improving individual opportunities for science would have a double benefit: less people's talent would be wasted, and diminishing returns to idea production would be (partially) offset.

First, we show two preliminary results that point to the same fact, namely the production of science becomes harder over time. First, we estimate the evolution of the age of the scientists at the time they accept the Nobel Prize which proxies the moment when the research community publicly agrees that the new idea is a fundamental contribution to science. The age of the Nobel Prize winners at the time they accepted the award in humanities (literature and peace) and economics remains constant over the whole period, with the average being 63 years old in humanities (Fig. 8 in Appendix 1) (*p*-value of the linear slope: 0.511) and 67 years old in economics (*p*-value of the linear slope: 0.827). However, the age of the Nobel Prize winners in science increases significantly from 51.4 years old in 1901 to 72.0 years old in 2020 (Fig. 8 in Appendix 1) (*p*-value of the linear slope: 0.000) and in mathematics from 33.1 years old in 1936 to 37.7 years old in 2018 (*p*-value of the linear slope: 0.008).

A second symptom of the diminishing returns of the production of ideas is the evolution of the number of people receiving each award. A significant increase in the number of recipients of the Nobel Prize and Fields Medal could suggest that new ideas involve more people now because they are more complex, and the required techniques are more sophisticated. To verify this assumption, we calculate the number of award recipients per year in science (normalised by the number of fields, 3), humanities (normalised by 2), mathematics and economics (Fig. 9 in Appendix 1). While the number for humanities slightly moves around 1.1 (slope of the linear regression: 0.0013; *p*-value: 0.179), it significantly increases for science (slope of the linear regression: 0.0155; *p*-value: 0.000). In fact, the non-parametrically estimated number of recipients in science for 2020, 2.7, is already close to its maximum value (3). The number of recipients also increases significantly for mathematics (slope of the linear regression: 0.0265; *p*-value: 0.000) and economics (slope of the linear regression: 0.0164; *p*-value: 0.009).

Now we try to find direct evidence of the increase in the average age of the scientists at the time of the breakthrough. For this task, we focus on the whole sample of researchers, although the results are similar when we use only those researchers whose main writings were published over a period of four years or less (see Table 3 in Appendix 2). We adopt the following empirical model:

$$Age_{i} = \alpha + \beta_{0} Year_{i} + \beta_{1} Year_{i}^{2} + \delta Field_{i} + \lambda_{0} GDPpc_{i} + \lambda_{1} Tertiary_{i} + \lambda_{2} Life_{i} + \lambda_{3} Mobility_{i} + \lambda_{4} Woman_{i} + \lambda_{5} Parent_{i} + \varepsilon_{i}$$
(2)

where Age_{*i*} is the age of individual *i* at the time of the breakthrough (age span for science: 21–71), Year_{*i*} is the year of the breakthrough (time span for science: 1871–2013), and Field_{*i*} represents the field-fixed effects (physics is the field of reference). The place of birth is represented by the real GDP per capita (GDPpc_{*i*}), the enrolment rate in tertiary education (Tertiary_{*i*}) and the life expectancy (Life_{*i*}) of the researcher's country at the year of birth; Mobility_{*i*} is a dummy variable that equals 1 if the country of birth is different from the country of the alma mater.⁷ In addition, Woman_{*i*} and Parent_{*i*} represent gender and parental occupation (class 6, the least favourable occupational category, is the class of reference), and ε_i is an i.i.d. error term.

Our strategy is to begin with the year of the breakthrough and then additional dimensions are added one by one to see if its influence is eliminated when other possible explicative factors like fixed effects and individual circumstances are included. Because all explicative variables, the year of the breakthrough, mobility and individual circumstances (place of birth, gender and parental occupation) are predetermined, we do not expect the existence of endogeneity or double causality. Consequently, we run field fixed-effects regressions where we control for unobservable characteristics using up to five fields: physics (omitted), chemistry, medicine, mathematics and economics. Results are presented in Table 1.

In model (1) we observe that the mean age at the time of the breakthrough is significantly increasing over time. In fact, the estimated linear trend goes from 33.6 years in 1871 to 43.8 years in 2013. These numbers (mean age at the breakthrough for the whole period: 39.3 years) are consistent with the studies of age and scientific output which consistently find that performance peaks in middle age, often in the late 30 s or early 40 s (Jones, 2010; Lehman, 1953; Simonton, 1991). More importantly, we find in model (2) that this aging phenomenon is accelerating, i.e., the age at the time of the main discovery is increasing exponentially, not linearly (Fig. 1). This acceleration of aging is maintained when field-fixed effects are included (model 3). In this case, note that the age at the time of the break-through is significantly lower in physics than in chemistry and medicine.

These results indicate that the production of science becomes harder over time, although this phenomenon is not linear but exponential. Consequently, to maintain the pace of scientific progress we need to offset the diminishing returns in the production of ideas by increasing the use of people's talent.

Next, we consider the role of the country of birth. As a first step, we consider this individual circumstance as a mere fixed effect (model 4). It is observed that when the countries of birth are grouped by geographical regions (Western Europe, Western offshoots,

⁷ We use the country of the alma mater instead of the country of residence in the year of winning the award to avoid endogeneity problems.

Table 1 The age	at the time of	the breakthroug	gh							
	Dependent	variable: age at	breakthrough							
	(1)	(2)	(3)	(4)	(5)	(9)	(7)	(8)	(6)	(10)
Year of break- through	0.0717^{***} (0.0107)	-3.7726*** (1.2303)	-3.6508*** (1.2129)	-3.5048^{***} (1.2204)	-8.1899 *** (1.5080)	-8.0621*** (1.5039)	-8.1036^{***} (1.5040)	-7.6311*** (1.5594)	-5.1245^{***} (1.4326)	-5.3570*** (1.3483)
Year of		0.0010^{***}	0.0010^{***}	0.0009***	0.0022***	0.0021^{***}	0.0021^{***}	0.0020***	0.0014***	0.0014***
breakthrough ²		(0.0003)	(0.0003)	(0.0003)	(0.0003)	(0.0004)	(0.0004)	(0.0004)	(0.0004)	(0.0004)
GDP per capita					0.0002 (0.0002)	0.0001 (0.0002)	0.0001 (0.0002)	0.0001 (0.0002)	-0.0000 (0.0001)	-0.0001 (0.0001)
Tertiary Educa- tion (%)					0.4500 * * * (0.0923)	-0.4386*** (0.0922)	-0.4171^{***} (0.0941)	-0.4276^{***} (0.0971)	-0.2618^{***} (0.0743)	-0.2578*** (0.0698)
Life expectancy					-0.4028***	-0.4127***	-0.4132***	-0.3772***	-0.3681***	-0.3616***
					(0.0572)	(0.0572)	(0.0571)	(0.0604)	(0.0572)	(0.0529)
Mobility						-2.5480^{**} (1.1821)	-2.5925 ** (1.1825)	-2.1459*(1.1964)	-2.1960 ** (1.1077)	-2.1461** (1.0424)
Female							-2.0543	-2.0028	-2.9189	-1.9980
							(00001)	(0000T)	(C00/T)	
rarental Occ.: class 1								4.0202 (1.7520)	(1.7765)	(1.6264)
Parental Occ.:								1.3046	0.9697	1.0107
class 2								(1.6103)	(1.6226)	(1.5027)
Parental Occ.: class 3								2.2243 (1.3765)	1.7662 (1.4081)	1.4786 (1.2984)
Parental Occ.:								2.5078*	1.9389	1.9777
class 4								(1.4871)	(1.5040)	(1.3730)
Parental Occ.: class 5								1.3050 (1.7576)	0.9332 (1.7678)	1.1484 (1.6492)
FE: Chemistry	I	ļ	3.0368***	2.9685***	2.4153***	2.5319***	2.5780***	2.6446^{***}	2.4623***	2.4059***
			(0.7869)	(0.7883)	(0.7826)	(0.7817)	(0.7826)	(0.8056)	(0.8070)	(0.7944)
FE: Medicine	I	I	3.1215*** (0.7509)	3.0809^{***} (0.7572)	2.8322*** (0.7436)	2.7850*** (0.7413)	2.8990*** (0.7481)	3.1961*** (0.7722)	2.9764^{***} (0.7681)	2.9246*** (0.7563)

	Dependen	t variable: age	at breakthrough							
	(1)	(2)	(3)	(4)	(5)	(9)	(2)	(8)	(6)	(10)
FE: Mathemat- ics	I	I	I	I	I	I	I	I	-7.9685*** (1.3546)	-8.0668*** (1.3289)
FE: Economics	I	I	I	I	I	I	I	I	I	0.3098 (0.9873)
FE: Region of birth	I	I	I	Yes	I	I	I	I	I	I
Adj. R ²	0.066	0.079	0.107	0.106	0.277	0.282	0.282	0.280	0.313	0.317
F-test	44.92	27.66	19.71	9.23	29.80	26.84	24.01	14.61	16.8	18.28
<i>p</i> -value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Obs	624	624	624	624	527	527	527	490	522	597
Observations ref enrolment in tert (reference), Easte	er to all rest tiary educati ern Europe,	earchers (breakt ion (%), and lift Latin America,	throughs are me e expectancy ar Asia, and Afric	easured by the 1 e measured for a. A constant is	middle year of 1 the researcher' included in all	the interval bety s country at the regressions and	ween the early a s year of birth.] I FE refers to fix	and late dates of Region of birth: ed effects. $*p < 0$	achievement). Rea Western Europe, V 0.1, **p < 0.05, ***	<pre>1 GDP per capita, Vestern Offshoots 'p < 0.01</pre>





Eastern Europe, Latin America, Asia and Africa) the main result is basically the same. This approach, however, disregards the socioeconomic conditions existing in a given country at the time of birth. For this reason, we introduce instead the level of development (real GDP per capita), the supply of higher education (enrolment rate in tertiary education) and the health conditions (life expectancy) of the researcher's country at the year of birth (model 5). Among the three factors representing opportunities by country of birth, the variables of education and health have a significant and robust negative effect on the age at the time of the breakthrough. It seems, therefore, that the average age of scientists at the time of the breakthrough is higher for researchers from less developed countries. Also, note that this result invalidates the idea that age at the time of the breakthrough increases over time due to the boost in life expectancy.

Geographical mobility between the birthplace and the country of the alma mater helps to reduce the age at the time of the breakthrough (model 6). Regarding opportunities by gender (model 7) and parental occupation (model 8), we find that being a woman does not affect the age at the time of the main discovery, while having parents from the wealthiest class significantly delays the breakthrough. Having parents from class 4 also increases the age at the time of the breakthrough, although this result is not robust (see also Table 3 in Appendix 2). It seems that top-class scientists from the wealthiest class take longer to develop their research careers, possibly because their financial needs are lower. This result implies that improving research opportunities for those individuals with bad parental background may reduce not only the waste of talent but also the period of time that a break-through takes on average.

When mathematics is also included (model 9), the results are similar. In addition, it is observed that the age at the time of the breakthrough is significantly lower in mathematics than in physics, chemistry and medicine, although this result is caused most probably by the existing upper limit to receive this prize (40 years). Finally, we show for robustness the results when economics is also considered (model 10). The results remain the same.

In sum, the production of science becomes harder over time and, for this reason, scientists make their main contribution when they are older. In addition, unequal opportunities due to the place of birth and parental occupation significantly influence the age at the time of the breakthrough.

Individual opportunities in science at the highest level

Scientists can move from their country of origin to other countries with better scientific infrastructures, intellectual environments and salaries. In fact, geographical mobility – between the country of birth and the country of residence in the year of winning the award – has accelerated over time (Fig. 10 in Appendix 3).⁸ As a result, the country of birth and the country of residence play considerably different roles. The country of birth reveals the geographical opportunity that individuals have to work in science, while the country of residence points out the countries which attract the most talented scientists in the world.

⁸ In all fields, the evolution of mobility is convex, which means that geographical mobility has accelerated over time. In particular, mobility significantly increased after World War II, but above all, during the last four decades (50% of mobility in science and humanities took place after 1978 and 1980, respectively, see Fig. 10 in Appendix 3).



Fig. 2 Opportunities to be a top-class scientist in the world by country of birth. *Note*: Lorenz curves of science (physics, chemistry and medicine) and humanities (literature and peace). Opportunities are the percentage of awards per capita by country of birth and the world population in 2015 is from United Nations (2017)

There is inequality of opportunity if the probability that an individual has to become a scientist capable of doing major research depends on personal traits (called *circumstances*) that are unalterable by one's own effort (Fleurbaey, 2008; Roemer, 1998). Consequently, there exists inequality of opportunity by country of birth if the probability that an individual has to become a top-class scientist in the world depends on his/her country of origin.

First, we proxy the probability that a person *i* born in country *h* has to become a topclass scientist in the world (p_i^h) by the percentage of awards per capita of his/her country of birth, i.e., $p_i^h = \frac{B_h/B}{N_h}$ where B_h and N_h denote the number of awards and the population of country *h* and *B* defines the total number of awards. We consider the percentage of awards per capita instead of the number of awards per capita $\left(\frac{B_h}{N_h}\right)$ to guarantee that total probability sum one.⁹ Then, we calculate global inequality (Milanovic, 2015) by computing the Lorenz curve $L_p\left(\frac{j}{N}\right) = \sum_{i=1}^{j} p_i^h$ where $1 \le j \le N$ (world population). To isolate the analysis from demographic issues, we use the world population in 2015 (United Nations, 2017).

We observe that the Lorenz curve is extremely skewed to the right, which implies an astonishing geographical inequality in the opportunity of becoming a top-class scientist (Fig. 2). Thus, the corresponding Gini coefficient is extremely high: G=0.88 (Table 2a). To give an idea of the significance of this value, we should recall that the Gini coefficient of global inequality (worldwide income distribution) was 0.61 in 2019 (Gradín, 2021).¹⁰

⁹ We know that all individuals from the same country have the same probability of being a top-class scientist in the world since we are considering here only the place of birth. Then, total probability, $P = \sum_{i=1}^{N} p_i^h$, can be rewritten as $P = \sum_{h=1}^{H} \frac{B_h/B}{N_h} N_h$ where N and H are the total population and total number of countries in the world, respectively. Then, it is straightforward to see that P is equal to one.

¹⁰ In the absence of a global survey of incomes, estimates of global inequality have to combine data from national surveys. Gradín (2021) rely on a new integrated dataset that aggregates standardized country income distributions at the percentile level estimated from various sources in the World Income Inequality Database (WIID).

Physics	Chemistry	Medicine	Science	Literature	Peace	Humanities	Economics	Maths
a. Inequality of i	ndividual opportunit	ies by country of bir	th (Gini index)					
0.881 (0.041)	0.897~(0.036)	$0.885\ (0.036)$	0.876 (0.032)	$0.856\ (0.033)$	0.839 (0.039)	0.817 (0.037)	0.920(0.038)	0.865 (0.036)
b. Probability ra	tio of becoming a top	o-class scientist betw	een men and women					
53.00 (45.74)	25.57 (16.26)	17.50 (5.73)	26.13 (5.86)	6.80 (2.06)	5.29 (1.52)	6.00 (1.16)	42.00 (27.62)	59.00 (24.41)
c. Inequality of i	ndividual opportunit.	ies by parental occul	pation (Gini index)					
0.517 (0.042)	0.480~(0.046)	0.485(0.039)	0.491 (0.025)	0.397 (0.053)	0.251 (0.050)	0.327 (0.039)	0.559 (0.052)	0.690(0.064)
d. Probability ra	tio of becoming a top	o-class scientist betw	ven the three most fa	woured and the thr	e most disfavoured	parental occupation	categories	
2.40 (0.39)	2.26 (0.37)	2.17 (0.33)	2.27 (0.20)	1.47 (0.28)	1.13 (0.17)	1.30 (0.17)	1.42 (0.32)	3.44 (1.62)
Science represer awarded to intern ard errors (500 r	tts physics, chemistry attional organization phications) in parent	/ and medicine; hum s (not used). Fields l hesis	anities are literature Medals (Maths) start	and peace. Nobel I ed in 1936 but are :	rizes for economics awarded on a regula	s were initiated in 19 r basis since 1950 (e	069. 28 Nobel Peace every four years). Bo	Prizes have been otstrapped stand-

 Table 2
 Inequality of opportunities in science



Fig. 3 Opportunities for science, Olympic medals, and patent applications. *Note*: Lorenz curves of science (physics, chemistry and medicine), Olympic medal winners in Olympic Games celebrated in summer and patent application rates. Opportunities in science are the percentage of Nobel Prize awards per capita by country of birth, opportunities for winning an Olympic medal are the percentage of medals per capita by country of origin, and opportunities to make a patent are the percentage of patent applications rates per capita by country of residence (1985–2015). The world population in 2015 is from United Nations (2017).

When comparing science with humanities, we find that the later dominates (in the sense of Lorenz) the former for the major part of the distribution (until percentile 96). As a result, opportunities are distributed more equally for literature and peace (G=0.82). The difference could be explained, at least in part, by the fact that becoming a scientist requires a significantly high level of good education which is costly and not available everywhere. Thus, 96% of the laureates in science, 100% in mathematics and 97% in economics have a master's degree and/or a PhD, while only 29% of laureates in humanities have a master's degree and/or a PhD.

In terms of fields, the Lorenz curves of mathematics, physics, chemistry and medicine cross each other (unanimous ranking cannot be established), although the first two of them dominate economics (Fig. 11 in Appendix 4). Meanwhile, literature and peace cross each other at different parts of the distribution (Fig. 12 in Appendix 4). In accordance with the previous Lorenz curves, opportunities by birthplace are very unequal (Table 2a). From the highest Gini coefficient to the lowest, we find the following ordering: economics (G=0.92), chemistry (G=0.90), medicine (G=0.89), physics (G=0.88), mathematics (G=0.87), literature (G=0.86), and peace (G=0.84).

To contrast the distribution of opportunities in frontier scientific achievement by country of birth with other indicators of talent, we calculate the Lorenz curve and Gini coefficient in the distribution of opportunities to win an Olympic medal and to make a patent application. Following the strategy explained above, we compute the percentage of Olympic medals and patents per capita across countries. For this task, we consider all the Olympic Games celebrated in summer (included Tokyo 2020) and use the total number of medals, since differences in inequality between the three types of medalists (gold, silver, and bronze) are not significant (results are available upon request). For patent outputs, we consider the number of patent applications from residents of a given country per million residents from 1985 to 2015 (Our World in Data, 2021). The results are shown in Fig. 3.

When comparing Nobel Prize winners in science with Olympic medalists, we find that the former group is distributed more unequally than the later. Thus, the distribution of Olympic winners dominates the Lorenz curve of science until percentile 99 and has a lower Gini coefficient (G=0.81). It seems, therefore, that the opportunity of becoming a topclass scientist in the world is lower than the opportunity of becoming an Olympic medalist. This broader context gives us a clear idea on how unequal opportunities in science by country of birth are. On the other hand, the level of inequality in the opportunities to make a patent (by country of residence) is even higher (G=0.91). The institutions of the country of residence are probably fundamental when it comes to transforming ideas into patent applications. Not only does it require the appropriate infrastructures and educational system, but also a significant amount of money to finance its high costs.

Individual opportunities for science are severely restricted by the birthplace, but is this circumstance the only personal trait that keeps people's talent out of science? The probability of carrying out research of the highest level should not depend on the gender of the individual. However, the fact of being a woman is a significant deterrent when it comes to working in science. We proxy the probability of becoming a top-class scientist of a man and a woman with the percentage of male and female winners, respectively, and then, calculate the ratio between these probabilities.¹¹ We observe that the probability of a woman. Meanwhile, the value of this ratio for humanities is only 6 (Table 2b). When fields are compared, we find that the ratio for mathematics (59), physics (53), economics (42), chemistry (26) and medicine (18) is very high and significantly bigger than the ratio for literature (7) and peace (5).

The probability of carrying out research of the highest level should also not depend on the socioeconomic origin of the individual, because otherwise unequal background could cause the waste of talent of underprivileged individuals.¹² To proxy these probabilities we use the percentage of awards in each parental occupation category (6 in our case). Then, inequality of opportunities caused by parental background is approximated by the inequality (Gini index) of estimated probabilities.¹³ From Table 2c it is clear that opportunities in science are significantly unequal with G=0.49. The Gini coefficient for economics is 0.56, being even higher for mathematics (0.69) since there are no winners with parents belonging to the lowest occupational category (elementary worker). On the contrary, opportunities to write and promote peace by parental background are significantly more equally distributed, G=0.33.

Among all parental occupations, one that represents mid-range economic resources, the teaching professional (at any level of the education system), significantly increases the probability of becoming a great scientist. Thus, 38.3% of parents (father, mother or both)

¹¹ Historically, research has consistently found that boys naturally outnumber girls at birth in all countries of the world. In the absence of gender discrimination or interference, the expected sex ratio at birth in the world is 1.05 (World Health Organization, 2020), although this value can range from 1.03 to 1.07. This ratio between boys and girls is important, but when it is compared to our ratios (Table 2c), it becomes irrelevant. In addition, it has been found that males are more likely than females to die in childhood. Consequently, we assume that the number of men and women capable of doing top research should be the same (ratio of 1).

¹² Socioeconomic origin (parental occupation or parental education) has been found to be one of the most important individual circumstances determining income inequality of opportunity (Rodríguez, 2008; Ferreira and Gignoux, 2011; Chechi and Peragine, 2010; Marrero and Rodríguez, 2011, 2012, 2013; Palomino et al., 2019).

¹³ There are 6 categories of parental occupations, so we multiply by $\frac{6}{5}$ the Gini coefficients resulting from the calculation of inequality of opportunity in science by parental occupation to convert their range from 0 to 1 (recall "The Nobel prize (1901–2020) and Fields Medal (1936–2018) databases" section).

of those who received an award in mathematics were teachers. The percentage for science and economics -24.7% and 22.1%, respectively is also high and significantly larger than the one for humanities, 13.8%. This result highlights that parental occupation plays an important role for scientific careers not only because of the required economic resources, but also because of the transmitted values and beliefs. Human curiosity is fundamental for the scientific quest, and teachers prompt children's curiosity more than any other parental occupation.

The previous measure of inequality of opportunity does not tell us about the parental occupational categories that provide better opportunities for research. To compensate for this shortcoming, we calculate the ratio between the probabilities of doing top science for the individuals with parents belonging to the three most favoured occupational categories and to the three least favoured categories (Table 2d). In the field of science, we clearly appreciate that the probability of an individual with parents belonging to the most favoured occupational categories more than doubles the probability of an individual with parents belonging to the least favoured occupational categories (the ratio is 2.3). For mathematics the differential is even worse with a ratio equal to 3.4, whereas the ratio of probabilities for humanities (1.3) points to a one-to-one relationship. For economics the ratio of probabilities is 1.4. The socioeconomic background of individuals is important for science and mathematics, the latter being the most elitist.

Opportunities in research over time

Research intensity has significantly increased over the last century. For example, the number of effective researchers rose by a factor of 23 (an average growth rate of 4.3 percent per year) between 1930 and 2014 in the U.S. (Bloom et al., 2017). Likewise, in the majority of countries, human capital per capita associated with formal education has increased substantially since 1870. Thus, primary education enrolment in the world has reached 91 per cent in 2015 (UNICEF, 2018) and the level of inequality (Gini coefficient) in the average years of primary, secondary, and tertiary schooling between countries has not stopped decreasing since 1870 (see Fig. 13 in Appendix 5). Have opportunities in science at the highest level evolved in the same way? Surprisingly, the answer is no.

New discoveries build on previous discoveries, i.e., science is cumulative. Accordingly, a new idea is affected not only by the opportunities that its creator had, but also by the opportunities that other scientists had before. For this reason, we propose a set of opportunity indices that are cumulative over time. The three dimensions that we will consider are: the place of birth (geographical opportunity), sex (gender opportunity) and parental occupation (background opportunity). Moreover, we take the year of birth as the appropriate reference to follow the evolution of opportunities in science at the highest level. None-theless, we replicate for robustness the whole analysis using the year of award as reference. Finally, to isolate our analysis from demographic changes, population is considered for a given year (2015).

Assume that the size of the world population is N and that N_j is the population of country *j*. Let B_t denote the total number of awards received by researchers born before t + 1 and B_{jt} be the number of awards received by scientists born before t + 1 in country *j*. Consequently, $c_t = \frac{1}{N} \sum_{j \mid B_{jt} \geq 0} N_j$ denotes the average coverage of the best possible science in the world (proxied by the reward of a Nobel Prize) in year *t*. However, since coverage across countries can be very different, we also need to consider the degree of dissimilarity



Fig. 4 Geographical opportunities over time. *Note*: Evolution of geographical opportunities over time: Panel **a** Equality of opportunity (Op_t^{P}); Panel **b** Inequality of opportunity (Gini coefficient in the accumulated percentage of awards per capita between countries). Time span: 1835–1974 for science, 1817–1997 for humanities, 1897–1987 for mathematics, and 1895–1972 for economics. Quadratic trends for science and humanities (panel a) are calculated from the first year with a positive value

in this coverage (Barros et al., 2009). For the set of countries with at least one award in year *t*, let $\eta_t = \sum_{j|B_{j_t}\rangle 0} N_j$ denote the aggregate population, p_{jt} denote the probability that an individual born before t + 1 in country *j* has to be a top-class scientist, and $\overline{p}_t = \sum_{j|B_{j_t}\rangle 0} \frac{N_j}{\eta_t} p_{jt}$ be the average probability. Then, $H_t = \frac{1}{2\overline{p_t}} \sum_{j|B_{j_t}\rangle 0} \frac{N_j}{\eta_t} |p_{jt} - \overline{p_t}|$ is the (normalised and population weighted) average deviation in top research coverage from the world mean, across the countries with at least one award in year *t*. We can proxy p_{jt} by $\frac{B_{jt}}{\eta_t}$, and the geographical opportunity index is defined as:

$$Op_t^G = c_t (1 - H_t) \text{ where } H_t = \frac{1}{2} \sum_{j \mid B_{ij} \mid 0} \frac{N_j}{\eta_t} \left| \frac{B_{jt} / N_j}{B_t / \eta_t} - 1 \right|$$
(3)

The geographical opportunity index, $Op_t^G \in [0, 1]$, is the average access to the best possible science in the world, penalised by the degree of dissimilarity in that coverage across countries in year *t*.

Geographical opportunities in science at the highest level are low (no greater than 0.20), and stable around 0.19 since 1920 (time span: 1835–1974). In fact, the evolution of this variable shows a clear exhaustion (concavity) of access to the best science in the world (Fig. 4, panel a). Similar size and trend are also observed in mathematics (time span: 1897–1987, Fig. 4, panel a) and economics (time span: 1895–1972, Fig. 4, panel a), whereas the evolution



Fig. 5 Gender opportunities over time. *Note*: Evolution of gender opportunities over time: Panel **a** Equality of opportunity (Op_t^S); Panel **b** Inequality of opportunity (accumulated percentage of awards ratio between men and women). We do not show the results of the ratio when the accumulated percentage of awards of women is zero because the ratio is infinite in this case. Time span: 1835–1974 for science, 1817–1997 for humanities, 1897–1987 for mathematics, and 1895–1972 for economics. Quadratic trends for science and humanities (panel a) are calculated from the first year with a positive value

of geographical opportunity in humanities (time span: 1817–1997) exhibits a process of exponential growth (convexity).

These results are consistent with the evolution of the Gini coefficient in opportunities between countries over time. Despite that our index, Op_t^G , captures geographical equality of opportunity and fulfils some desirable properties, we also calculate the Gini coefficient in the (accumulated) percentage of awards per capita between countries over time because it is more intuitive. Thus, while Op_t^G measures geographical equality of opportunity, the corresponding Gini coefficient estimates geographical inequality of opportunity. The trend of the Gini coefficient for science and humanities is presented in Fig. 4 (panel b). We observe that the Gini coefficient in opportunities for science decreases approximately until 1920 and is stable around 0.88 since then. In the initial year, the Gini coefficient is equal to 1 because only one country has a Nobel Prize winner. The results for mathematics and economics are similar (Fig. 4, panel b).

Now, let W_t and M_t denote the total number of awards received by women and men born before t + 1, respectively. By using the *minimum function* (Roemer, 1998) the sex opportunity index is defined as:

$$Op_t^{\rm S} = \frac{2}{B_t} \min\left\{W_t, M_t\right\},\tag{4}$$



Fig. 6 Background opportunities over time. *Note*: Evolution of background opportunities over time: Panel **a** Equality of opportunity (Op_t^B) ; Panel **b** Inequality of opportunity (Gini coefficient in the accumulated percentage of awards between parental occupation categories). Time span: 1835–1974 for science, 1817–1997 for humanities, 1897–1987 for mathematics, and 1895–1972 for economics. Quadratic trends for science and humanities (panel **a**) are calculated from the first year with a positive value

where by definition $Op_1^S \in [0, 1]$. Gender opportunity in science is at its maximum when men and women share the awards equally. Consistent with the previous evidence, however, gender opportunity in science is very low (Fig. 5, panel a). Worse still, it has remained stable around 0.05 since 1870. On the contrary, gender opportunity in humanities has increased significantly since 1860. In mathematics and economics opportunities by sex are almost zero since only a very few women (1 in mathematics and 2 in economics) have received the award.

For robustness, we also calculate the evolution of the probability ratio between men and women over time, although for the first decades, when women have no awards, we do not compute this ratio to avoid infinites (see Fig. 5, panel b). We observe that, despite the high variation in the probability ratio, gender inequality of opportunity in science is at the same level than gender inequality at the beginning of the period. The same trend is observed for economics. Meanwhile, gender inequality of opportunity in humanities decreases throughout the whole period and in mathematics, if anything, there is an increase in inequality of opportunity over time.

Let B_{kt} denote the number of awards received by scientists with parental occupation k, where k = 1, 2, ..., 6, born before t + 1. Because being a top-class scientist should not depend on the socioeconomic origin of the individual, we define the background opportunity index as:

$$Op_t^B = \frac{6}{B_t} \min \left\{ B_{kt} \right\}_{k=1}^6$$
(5)

This index, $Op_i^B \in [0, 1]$, which is low (no greater than 0.40) and similar for both science and humanities, increased from 1891 to 1951, declining ever since (Fig. 6, panel a). In mathematics, since there are no winners with parents belonging to the lowest occupational category (elementary worker), background equality of opportunity remains at its minimum value of zero all the time (Fig. 6, panel a). In economics opportunities by parental occupation have remained low and stable (around 0.22) for the last period (1950–1972). For robustness, we also estimate the evolution of the Gini coefficient in opportunities between parental occupation categories over time. The trend of the Gini coefficient is presented in Fig. 6 (panel b). We observe that background inequality of opportunities in science is stable around 0.48 since 1900 while, in mathematics, it is increasing since 1940.

To complement our analysis, we also develop a summary measure of equality of opportunities in the three previous dimensions: birthplace, sex and background. The Opportunity index (OPI) is the geometric mean of normalised indices for each of the three dimensions. Unlike the arithmetic mean, the geometric mean rewards overall balance since it penalizes inequality in achievements across dimensions.¹⁴ Given the limitation imposed by the circumstance of sex (only two types, men and women), the dimension indices are calculated as:

$$I_t = \frac{2}{B_t} \min\left\{D_t, E_t\right\} \tag{6}$$

For the birthplace dimension, D_t denotes the total number of awards received by scientists born in the G-5 countries (the United States, the United Kingdom, Germany, France and Japan) before t + 1, while E_t denotes the total number of awards received by researchers born in the rest of the world before t + 1.¹⁵ For the gender dimension, $D_t = W_t$ and $E_t = M_t$. Finally, for the background dimension, D_t and E_t denote the total number of awards received by scientists born before t + 1 whose parents' occupation belongs to the three most favoured occupational categories and the three least favoured ones, respectively.

The OPI is the geometric mean of the three dimensional indices:

$$OPI_{t} = \left(I_{t}^{\text{birthplace}} \cdot I_{t}^{\text{gender}} \cdot I_{t}^{\text{background}}\right)^{\frac{1}{3}}$$
(7)

Opportunities in science measured by $OPI_t \in [0, 1]$ have remained stable at approximately 0.28 since 1896, whereas opportunities in humanities have increased significantly, from 0.42 in 1870 to 0.57 in 1997 (Fig. 7). In mathematics, opportunities have been zero until very recently because the only woman who has received the Fields Medal was born in 1977 (Fig. 7). Meanwhile, opportunities in economics have decreased from 1933 until very recently.

Our results show that opportunities in science and humanities have remained low for the whole period under analysis. However, their evolution has been significantly different. Opportunities in humanities, regardless of the dimension (geography, sex or parental occupation), have increased since 1866, while opportunities in science have stagnated. If we consider the

¹⁴ For an axiomatic justification of this type of multiplicative indices see Kawada et al. (2019).

¹⁵ The results are similar when we consider only the US, the UK and Germany in D_t .



Fig. 7 The OPI over time. *Note*: Evolution of the Opportunity index over time. Time span: 1835–1974 for science, 1817–1997 for humanities, 1897–1987 for mathematics, and 1895–1972 for economics. Quadratic trends for science and humanities are calculated from the first year with a positive value.

year of award, instead of the year of birth, as the most appropriate reference to follow the evolution of opportunities in science at the highest level, the time span will change (1901–2019) but the evolution of opportunities will remain basically the same across dimensions (see Figs. 14, 15, 16, 17 in Appendix 6). It seems therefore that despite the larger complexity of new ideas and the higher sophistication of the new methods of verification, which require the work of many more scientists regardless of their birthplace, sex and socioeconomic origin, opportunities in science at the highest level have stagnated.

Concluding remarks

The same idea can be used by all individuals because ideas, which are the main driving force of economic growth (Mokyr, 2017), are non-rivalrous. As a result, the number of individuals with enough opportunities to create new ideas in the world, not in a given

country, is determinant for the advancement of science and the economic development of human societies. The larger the pool of people science has to draw on, the greater the number of individuals that can have new ideas (potential supply of ideas). But people are only a necessary condition for research, not a sufficient one, because individuals have to be capable of creating new ideas (observed supply of ideas). For example, the Industrial Revolution ("take-off") occurred in Europe instead of China despite the fact that the latter was far more populated for two millennia.

The findings of this study demonstrate that, although geographical mobility of scientists significantly increased throughout the twentieth century, barriers in science were huge. First, the age at breakthrough was found to be negatively related to the average level of education (enrolment rate in tertiary education) and health (life expectancy) in the researcher's country of birth. This result implies that the average age of scientists at the time of the breakthrough was higher for researchers from less developed countries. In the same way, opportunities by birthplace were found to be extremely unequal. In fact, becoming a top-class scientist in the world by country of birth was found to be harder than becoming an Olympic medalist. Gender was a significant deterrent for the scientific quest. And socioeconomic background kept many individuals out of a career in science. Thus, the probability of doing scientific research at the highest level of an individual with parents belonging to the most favoured occupational categories more than doubled the probability of an individual with parents belonging to the least favoured occupational categories.

These findings would not be so negative if opportunities in science had increased. Contrary to the expectations, our results showed that opportunities in science, in contrast with humanities, have suffered from stagnation. Geographical opportunities in science at the highest level were stable around 0.2 since 1920, being the trend for mathematics similar. Opportunities by gender in science remained stable around 0.05 since 1870, while opportunities by sex in mathematics kept close to zero during the whole considered period. Finally, background opportunity in science increased from 1891 to 1951, declining ever since. In mathematics, background opportunity remained at its minimum value of zero all the time.

To maintain the pace of innovation, more and better education, more sophisticated labs and installations, and stronger collaborations between scientists are necessary. These needs can create large opportunities for individuals to use their talent, regardless of their birthplace, gender and socioeconomic origin. However, these needs are costly so they can also progressively leave many countries and individuals behind. Our findings seem to highlight that the later possibility has been as important as the former since opportunities in science have suffered from stagnation. The large barriers that existed in science at the highest level have not been eliminated sufficiently fast to avoid the deceleration of innovation.

Appendix

Appendix 1: Age at award and awards per year

See Figs. 8 and 9.



Fig. 8 Age at award in science, humanities, mathematics and economics. *Note*: Age at the time the Nobel Prize and Fields Medal winners accept the award. Local linear smoothing (kernel: Epanechnikov). Shadow area: 95% confidence interval



Fig. 9 Awards per year in science, humanities, mathematics and economics. *Note*: Normalised number of awards per year. The maximum number of recipients in science, humanities and economics is 3, while it is 4 in mathematics. Local linear smoothing (kernel: Epanechnikov). Shadow area: 95% confidence interval

Appendix 2: The age at the time of the breakthrough

See Table 3.

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	Dependent v	variable: age at b	oreakthrough							
	(1)	(2)	(3)	(4)	(5)	(9)	(1)	(8)	(6)	(10)
Year of break- through	0.0708 *** (0.0117)	-4.0860 *** (1.3665)	-3.8601^{***} (1.3437)	-3.6515^{***} (1.3493)	-8.0863 *** (1.6490)	-7.9516*** (1.6410)	-8.0106^{**} (1.6442)	-7.7222*** (1.6895)	-6.3213*** (1.5959)	-6.8875*** (1.5405)
Year of breakthrough ²		0.0011^{***} (0.0004)	0.0010^{***} (0.0004)	0.0010^{***} (0.0004)	0.0021*** (0.0004)	0.0021*** (0.0004)	0.0021*** (0.0004)	0.0020*** (0.0004)	0.0017*** (0.0004)	0.0018^{***} (0.0004)
GDP per capita		~	~	~	0.0002	0.0001	0.0001	0.0001	-0.0001	-0.0002
Tertiary Educa-					-0.4246***	- 0.4092***	-0.3953***	-0.4188^{***}	(0.0002) -0.2769***	-0.2891 ***
tion $(\%)$					(0.0965)	(0.0962)	(0.0983)	(0.1013)	(0.0803)	(0.0774)
Life expectancy					-0.3577*** (0.0631)	-0.3650^{***} (0.0629)	-0.3653^{***} (0.0629)	-0.3438^{***} (0.0663)	-0.3335^{***} (0.0635)	-0.3482^{***} (0.0611)
Mobility						-3.0159^{**}	-3.0472^{**}	-2.7508^{**}	-2.9427**	-3.1667^{**}
						(1.2584)	(1.2599)	(1.2775)	(1.2531)	(1.2268)
Female							-1.3594	-1.2608	-1.5384	-1.1946
							(1.9669)	(2.0347)	(1.9909)	(1.8846)
Parental Occ.:								4.4472**	3.5098*	3.1375*
class 1								(1.8150)	(1.8410)	(1.6808)
Parental Occ.:								0.7279	0.3184	0.0257
class 2								(1.6606)	(1.6865)	(1.5677)
Parental Occ.:								1.4349	0.8201	0.3549
class 3								(1.4140)	(1.4504)	(1.3325)
Parental Occ.:								1.8267	1.2102	1.1183
class 4								(1.5378)	(1.5566)	(1.4300)
Parental Occ.:								1.4382	0.9449	0.4445
class 5								(1.7972)	(1.8101)	(1.7043)
FE: Chemistry	Ι	Ι	3.4693***	3.4255***	2.7891^{***}	2.9602^{***}	2.9924^{***}	2.9142^{***}	2.6696^{***}	2.5428***
			(0.8446)	(0.8446)	(0.8471)	(0.8455)	(0.8473)	(0.8738)	(0.8806)	(0.8643)
FE: Medicine	Ι	I	3.2957***	3.2053***	3.0322^{***}	2.9378^{***}	3.0141^{***}	3.2017^{***}	2.9603^{***}	2.8704^{***}
			(0.8077)	(0.8138)	(0.8049)	(0.8015)	(0.8096)	(0.8305)	(0.8268)	(0.8121)

Table 3 The age at the time of the breakthrough (interval < 5 years)

	Depender	nt variable: age	e at breakthrough	ų						
	(1)	(2)	(3)	(4)	(5)	(9)	(2)	(8)	(6)	(10)
FE: Mathemat- ics	I	I	I	I	I	I	I	I	-6.9128^{***} (1.5688)	-6.8639*** (1.5408)
FE: Economics	I	I	I	I	I	I	I	I	I	-0.6455 (1.2181)
FE: Region of birth	I	I	I	Yes	I	I	I	I	I	I
Adj. R^2	0.063	0.078	0.114	0.116	0.262	0.270	0.269	0.274	0.302	0.322
F-test	36.53	23.18	17.83	8.65	23.42	21.43	19.08	12.18	13.50	15.17
<i>p</i> -value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Obs	526	526	526	526	443	443	443	416	435	478
Observations ref measured for the A constant is inc	er to researc researcher's	chers whose by s country at th	reakthrough too ie year of birth.	k four years or Region of birth	less to be made. : Western Europ	. Real GDP per e, Western Offs ****~_001	capita, enrolme hoots (reference	nt in tertiary ed :), Eastern Eurol	ucation (%), and lif pe, Latin America,	e expectancy are Asia, and Africa

Scientometrics



See Fig. 10.



Fig. 10 Geographical mobility. *Note*: Geographical mobility between the country of birth and the country of residence in the year of winning the award. Values are accumulated and total mobility is normalised to 100%



See Figs. 11 and 12.



Fig. 11 Inequality of opportunities by scientific fields, mathematics and economics. *Note*: Lorenz curves of physics, chemistry, medicine, mathematics and economics. Opportunities are the percentage of awards per capita by country of birth and the world population in 2015 is from United Nations (2017)



Fig. 12 Inequality of opportunities in literature and peace. *Note*: Lorenz curves of literature and peace. Opportunities are the percentage of awards per capita by country of birth and the world population in 2015 is from United Nations (2017)

Appendix 5: Inequality in average years of schooling

See Fig. 13.



Fig. 13 Inequality in average years of schooling between countries over time. *Note*: Evolution of inequality in the average years of primary, secondary, and tertiary schooling between countries from 1870 to 2015. The estimates are the weighted Gini coefficient in average years of primary, secondary, and tertiary schooling for the population aged 15–64 of 111 countries where the weight is total population by country and year. The original data is from Lee and Lee (2016)



See Figs. 14, 15, 16 and 17.



Fig. 14 Geographical opportunities over time. *Note*: Evolution of geographical opportunities over time by the date of award. Time span: 1901–2020 for science and humanities, 1936–2018 for mathematics, and 1969–2020 for economics. Quadratic trends for science and humanities are calculated from 1905 to 2020



Fig. 15 Gender opportunities over time. *Note*: Evolution of gender opportunities over time by the date of award. Time span: 1901–2020 for science and humanities, 1936–2018 for mathematics, and 1969–2020 for economics. Quadratic trends for science and humanities are calculated from 1905 to 2020



Fig. 16 Background opportunities over time. *Note*: Evolution of background opportunities over time by the date of award. Time span: 1901–2020 for science and humanities, 1936–2018 for mathematics, and 1969–2020 for economics. Quadratic trends for science and humanities are calculated from 1905 to 2020



Fig. 17 The OPI over time. *Note*: Evolution of the OPI over time by the date of award. Time span: 1901–2020 for science and humanities, 1936–2018 for mathematics, and 1969–2020 for economics. Quadratic trends for science and humanities are calculated from 1905 to 2020

Acknowledgements I am grateful for assistance with the database from Fátima Morales, Joël Terschuur, Tania Barragán and María T. Sánchez. I also acknowledge suggestions of Oded Galor, David Weil, Gustavo Marrero, Elena Bárcena, Rafael Salas, Juan C. Palomino and Raquel Sebastián, and the participants at the Meeting of the Society for the Study of Economic Inequality ECINEQ (Paris), "Growth Lab" at Brown University (Providence, USA), EQUALITAS Workshop (Madrid, Spain), Meeting on "Equal Chances" (Bari, Italy), seminar at the Universidad de La Laguna (Tenerife, Spain) and XXVI Encuentro de Economía Pública (Oviedo, Spain). I am particularly thankful to an anonymous referee who helped me to improve this paper.

Funding Open Access funding provided thanks to the CRUE-CSIC agreement with Springer Nature. This work was supported by Ministerio de Ciencia e Innovación (Spain) [PID2019-104619RB-C42]; Comunidad de Madrid (Spain) [H2019/HUM-5793-OPINBI-CM]; and COTEC Foundation. Responsibility for any error is the author's alone.

Data availability The author declares that none of this material has been published or is under consideration for publication elsewhere. He compromises to deposit the built database underlying the study in your repository in the case the paper is accepted.

Code availability The corresponding do files will be totally available to researchers.

Declarations

Conflict of interest None.

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