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Social stratification in science: the ultra-elite in the UK

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ABSTRACT

We start out from Harriet Zuckerman's study of the US scientific ultra-elite of Nobel laureates, in which Robert Merton's idea of 'Matthew effects' as a key mechanism in the creation of social inequalities was first introduced. We then consider two issues arising from critical commentary on this study by Elisabeth Crawford, a historian of science. First, how far can a scientific ultra-elite be shown to exist as a collectivity that is socially distinctive? Second, how far is Zuckerman's account of the formation of the US ultra-elite trough 'bilateral associative selection' between scientific masters and their would-be apprentices historically specific to the US? In the UK case, we compare the social origins and educational careers of members of two possible scientific ultra-elites, defined by differing degrees of stringency, with those of other elite scientists. We find that as one moves from the elite to the less stringently defined ultra-elite, there is little evidence of increasing social stratification but that such evidence does emerge in moving to the more stringently defined ultra-elite. We also show through two contrasting Cambridge case studies, that the underlying social processes that Zuckerman identifies in ultra-elite formation in the US are also present in these UK contexts.

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Introduction

Harriet Zuckerman's study (1995 [1977]) of the social origins, education and career paths of Nobel laureates in the US was a pioneering analysis of social stratification in science: specifically, of the formation of what could

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be called the scientific ultra-elite. We take her work as the starting point for our own study on the formation of the scientific ultra-elite in the UK, for the following reasons.[1]

First, Zuckerman's study was to a significant extent organised around Merton's seminal proposal (1968) of 'Matthew effects'[2] as a major source of stratification in science – an idea later given a much wider application (see, e.g. DiPrete and Eirich 2006; Rigney 2010; Perc 2014; Bask and Bask 2015). A tendency exists, Merton argued, for scientific careers to be characterised by cumulative advantage in that scientists who achieve some early success in research are then likely to receive greater recognition and better opportunities for subsequent research than those who have yet to make their mark – and even if the latter do later produce research of comparable quality. Indeed, Zuckerman's interviews with American Nobelists could be regarded as the main empirical source out of which Merton's idea of the Matthew effect emerged.[3]

Second, Zuckerman, starting out from Nobelists at the peak of the scientific hierarchy seeks to show how in their cases Matthew effects actually operated – that is, through what social processes cumulative advantage and subsequent stratification came about.[4] In other words, Zuckerman provides what could be taken as a leading example of the development of Mertonian 'middle-range' theory in going beyond the empirical demonstration of a social phenomenon – the fact of stratification in science – to specify the 'generative mechanisms' underlying the phenomenon. This is a form of theory development now proving increasingly attractive and influential in sociology (see e.g. Hedström and Bearman 2009; Goldthorpe 2016: ch .9).

Third, Zuckerman's work has been contested by a historian of science, Elisabeth Crawford (1992), leading to a response from Zuckerman (1995 [1977]), and thus to the raising of a number of issues that are of importance beyond the particular case in dispute: that is, in bearing on

[1]Here and subsequently, 'science' should be taken as referring to the natural sciences.

[2]'For unto every one that hath shall be given, and he shall have abundance: but from him that hath not shall be taken away even that which he hath' (Matthew, 25: 29).

[3]In a footnote to a reprinted version of his paper, Merton (1973: 439) acknowledged his belated awareness that he drew on Zuckerman's research 'to such an extent that, clearly, the paper should have appeared under joint authorship'.

[4]Later research aimed at testing the idea of Matthew effects in science has not produced consistently confirmatory results. See, e.g. Allison *et al*. (1982) on studies of widening inequalities in publications and citations as birth cohorts of scientists age, and Azoulay *et al*. (2014) on the effect of scientists winning a prestigious prize on the subsequent citation of their work. More compelling is the finding of Bol *et al*. (2018) on early funding success and the chances of later success. However, such studies have not in any case gone far beyond statistical results to consider the social processes generating such Matthew effects as appear to occur.

differences between sociological and historical styles of explanation. This being the case, the dispute has received surprisingly little attention.

In the following section of the paper, we set out Zuckerman's account of the social processes through which she sees Nobel prize-winners as having typically gained cumulative advantage, relative to other scientists, over the course of their careers. We likewise set out Crawford's objections to this understanding of how an ultra-elite, in the form of Nobelists, emerged in American science, and we seek to clarify what are the most serious points on which Zuckerman and Crawford differ. We then explain why we see a study of the ultra-elite in UK science as being, as well as of interest in itself, also of potential relevance to the resolution of their dispute.

In the third section of the paper, we describe the data on which we will draw and explain how we deal with the problem of defining the scientific ultra-elite in the UK. In the fourth, we then consider empirically the first-order question of how far in the formation of an ultra-elite in UK science there is in fact evidence of social stratification that is at least suggestive of Matthew effects at work. We show that, for one version of such an ultra-elite, evidence does indeed exist in that its members appear advantaged in their social origins, and then further in their secondary schooling and in their undergraduate and postgraduate university education.

In the fifth section, following Zuckerman's observation that the processes involved in the formation of the scientific ultra-elite tend to converge in a limited number of centres, we report on two case studies, based primarily on documentary evidence, that are sited in Cambridge University, where convergence of the kind in question has on several occasions occurred. We ask how far in these cases the same processes that Zuckerman identifies in the formation of the US ultra-elite can also be found in a UK context.

In conclusion, we consider the implications of our findings for the controversy between Zuckerman and Crawford and for certain more general issues that arise.

Social stratification or decisions in Sweden?

Zuckerman's main line of argument is that in the formation of the American scientific ultra-elite, a process of what she terms 'bilateral associative selection' has been of major, if not exclusive, importance. What she here refers to (1995 [1977]: ch. 4) is the 'mutual search' of eminent scientists wanting outstanding graduate students and postdocs and ambitious young scientists wanting to work with the leaders in their fields. 'Master-apprentice' relations are thus created that develop into strong intergenerational links or 'filiations'. Under the influence of their masters – who are often what Merton (1960) calls 'evokers of excellence' – talented students are helped to identify, and are encouraged to study, 'big', if risky, problems. And, those whose initial work is successful will then be given privileged access to new research opportunities and resources through which their scientific reputations and career prospects are further enhanced – Matthew effects in operation. Subsequently, at the stage where the possibility of awards arises, masters can turn into patrons and sponsors, pushing the claims of their former students. Zuckerman gives numerous examples of Nobel laureates nominating their protégés for a Nobel prize and then lobbying, often strenuously, for them to receive it; and she documents how ten Nobelist masters could claim to have to their credit as many as 30 of the 71 American laureates she studied.

Social stratification can then be seen as likely to occur from an early stage: that is, from the very time when budding scientists are deciding where they should try to pursue their careers. What is important here is, first of all, that they should have some sense of the importance to their chances of future success of working with an elite, if not an ultra-elite, master. They then need further to know who such potential masters are in their particular fields of research interest and where they are located. And, finally, given the degree of competition they will face in being taken on by leading masters, it will be helpful to them if they have good guidance on how best to approach these individuals and their institutions, and more helpful still if they have relevant contacts or 'mediators'. In each of these respects, therefore, young scientists with socially advantaged, and especially professional, parents could be thought to be favoured. They are likely to have attended schools and universities that provide high quality scientific education and thus to be well-prepared academically and also, if need be, financially, for postgraduate work.[5] And, further, insofar as their parents are themselves scientists or in occupations in some way involving science, they are likely, as Zuckerman puts it (1995 [1977]: 108–9), to have been 'socialized in the ways of science', to have been 'tuned in early to the major channels of

[5]More generally, Morgan *et al.* (2022) show that US-based tenure-track university professors are about twice as likely as other individuals who hold a PhD to have a parent with a PhD. In addition, they also find that faculty with PhD parents are much more likely than other faculty to receive support and encouragement for their academic careers from their parents.

communication about new developments' in different fields, to be aware of possible masters with 'scientific talent of Nobel calibre' or even to have links with them through their families' social networks. Zuckerman notes (1995 [1977]: 66–7) that over half of the Nobelists she studied had fathers who were scientists, science teachers, engineers or physicians.[6]

Crawford's critique of Zuckerman stems from her own studies of the selection processes that are involved in the award of Nobel prizes. Since 1974, the Nobel Foundation has allowed access to documents in the archives of the Royal Swedish Academy of Sciences relevant to the awards of the prizes in physics and chemistry – although at a distance of fifty years. Crawford has taken a leading role in research based on these documents, analysing the parts played in the award of prizes by the nominators of candidates and by the members of the awarding committees, with special reference to the interplay of national and international influences.[7] In the light of her own work, she sees two shortcomings in Zuckerman's study.

First, Crawford questions the idea that American Nobelists are 'a breed set apart' in some social sense from the collectivity of other leading scientists in the US who failed to get a Nobel prize – even if in some number of cases having been nominated for one. What distinguishes the laureates is in fact little more than 'successive prize decisions by scientific corporations in Sweden'. In other words, processes of social stratification in science, whether involving Matthew effects or not, are of no great relevance. Any attempt to define in terms of social attributes an ultra-elite within the body of eminent scientists at large will, at best, show only a 'gradual fading' of the one into the other (1992: 128, 142–3). Second, Crawford contends that Zuckerman's account of the processes leading to the formation of the ultra-elite in American science cannot, in any event, have the general sociological significance that she wishes to claim for it. Zuckerman, Crawford maintains, treats her Nobelists as 'an ahistoric entity' (1992: 128), failing to recognise that the extent to which the institutional context within which their success was achieved was in fact place- and time specific.

As regards Crawford's first line of criticism, it must be said that Zuckerman does make it very clear (1995 [1977]: 42) that 'there has always

[6]A recent study of the social backgrounds and careers of successful American inventors (Bell *et al*. 2019) has notable parallels with Zuckerman's study in showing that not only are these inventors more likely to come from high rather than low income families but also from families and from local contexts in which they are 'exposed' to innovation during their childhoods.

[7]Work this tradition continues (see, e.g. Hansson and Schlich 2022). The historical restriction placed on such research is, however, a serious one.

been an accumulation of 'uncrowned' Laureates who are the peers of prize-winners in every sense except that of having the award'. And, following Merton (1968: 56–7), she repeatedly refers to 'the phenomenon of the 41st chair'.[8] Crawford and Zuckerman are in effect in agreement that *in terms purely of scientific achievement*, Nobelists cannot be sharply separated off from a range of other elite scientists. Where disagreement essentially arises is on the question of how the *de facto* distinction between laureates and non-laureates does then come about. For Crawford, it is the microsocial processes that go on before and during the meetings of the Nobel selection committees that are crucial. While Zuckerman would not deny that such processes play a part, she seeks to bring out the wider social processes of ultra-elite formation within the scientific community, involving stratification in various forms, which influence the chances of individuals *coming before the selection committees in the first place* – and which Crawford (1992: 143) would appear to find of little interest. In what follows, we will then focus on this more specific issue, with fuller data than Zuckerman was able to use.

As regards Crawford's second line of criticism, the difference between her and Zuckerman is more basic, with the historian challenging the validity of the sociologist's attempt at identifying social processes of some generality that can operate across different institutional contexts. We aim to contribute here by examining how far Zuckerman's analysis of the formation of the US scientific ultra-elite does find any correspondence in one other national case, that of the UK.

Data and definitions

Our data come from a prosopographical study – a study of collective biographies[9] – of the UK scientific elite (Bukodi *et al.* 2022) as represented by Fellows of the Royal Society born from 1900 onwards. The Royal Society was founded in 1662 and has been generally regarded as the pre-eminent British scientific association, election to which – through elaborate and stringent procedures (Royal Society 2023) – confers a high level of individual prestige and, potentially at least, considerable influence and power

[8]The reference is to the *Académie Française*, which is limited to the occupants of forty 'chairs', who are elected for life. Thus, many distinguished persons have never joined *les immortels*, if only because no appropriate chair became vacant before their deaths.

[9]Prosopographical studies have been widely used by historians in the study of elites (see, e.g. Stone 1971; Keats-Rohan 2007; Clark 2008) but, until recently, far less often by sociologists who have tended to rely on data sources that cannot provide information of the detailed kind for which the approach calls.

within the scientific community. As of now, the total membership of the Society is around 1700 but was smaller at all earlier periods. We make, however, the following exclusions: all Foreign Members, Honorary and Royal Fellows,[10] all deceased Fellows whose last employment prior to retirement was not in the UK, all living Fellows whose most recent employment was not in the UK, and all Fellows who would appear to have spent significantly more of their research careers outside of, rather than within, the UK. Our target population then numbers 2112 Fellows. We have sought biographical information on these Fellows from a wide range of sources. For deceased Fellows, we rely mainly on the Royal Society's *Biographical Memoirs* but also on the *Dictionary of National Biography*; and for living Fellows, mainly on results from an online survey carried out in late 2020, with an almost 70% response rate, but also on *Who's Who* and Debrett's *People of Today (2016)*. And, in the case of both the dead and the living we have further exploited web sources in the form of obituaries, interviews etc.

We have obtained full information on items of interest to us for 1681 Fellows, amounting, that is, to an 80% coverage of our target population. In Appendix 1, we provide further details. It can be seen that we are somewhat more successful in obtaining information on those in earlier than in later birth cohorts – that is, in effect, on the dead rather than on the living. Any serious selection bias in our coverage would therefore be likely to come about in this way. In Appendices 2 and 3, we show the results of tests we have made to see if differences exist *across cohorts* in the information we have for deceased and living Fellows on two key variables in our analyses: class origins and private versus state secondary schooling. The differences that show up are generally small. We therefore feel able to take our data as providing the basis for a prosopography of the Fellows in our target population that is free from any major bias sufficient to compromise our analyses. In other words, we take our results as being adequately descriptive of the *population* with which we are concerned, even if estimated from a somewhat incomplete set of observations. We do not therefore see significance testing as being appropriate.[11]

The question then arises of how, within the scientific elite we have studied, we should define an ultra-elite. We opt in fact to define, in the

[10]For definitions of these various categories, see: https://royalsociety.org/fellows/election/.

[11]If we were to suppose that our coverage amounts to an 80% sample of our population, and sought to engage in inference from sample to population, we would need to include some major finite population corrections, since 80% is such a large proportion of the whole (Cochran 1977). We cannot see that, in the present context, to proceed in this way would be at all illuminating.

first place, two possible ultra-elites, one of a more stringently constituted kind than the other. We aim in this way to see how far there is, in Crawford's words, only 'a gradual fading' of social differences between elite and ultra-elite is dependent on how the ultra-elite is understood.

Both possible ultra-elites are defined in terms of the receipt of prestigious awards. The line of division we draw is that between those Fellows whose achievement is limited to an award, eligibility for which is nationally limited, and those who have received one, or more, of a number of other awards that are given on a fully international basis – the competition for the latter being obviously stronger. Thus, our first ultra-elite – hereafter UE1 – comprises all Fellows in our target population who have received the Royal Society's Royal Medal, given only to scientists who are British, Commonwealth or Irish citizens or long-term residents,[12] but who have *not* received any of the international awards that we consider. Our second ultra-elite – hereafter UE2 – comprises all Fellows who, whether or not recipients of a Royal Medal, have gained, at least, one of these international awards. These are a Nobel Prize in Physics, Chemistry, or Physiology or Medicine or one of three other awards widely regarded as being of comparable distinction: an Abel Prize, a Fields Medal or a Copley Medal.

We thus differ from Zuckerman in going beyond Nobel prizes as the criterion of ultra-elite membership. This is because – as she herself recognises (1995 [1977]: xvi–ii) – the Nobels do not cover all fields of science. Most obviously, there is no Nobel Prize for mathematics. It was in fact with the intention of creating a Nobel equivalent for mathematics that the Abel Prize was established by the Norwegian government in 2002, and has since been awarded annually. However, the Fields Medal, inaugurated in 1936 and awarded every four years to between two and four mathematicians under the age of 40, is also widely regarded as a Nobel equivalent. Moreover, there are various other scientific fields apart from mathematics for work in which, as a matter of practice if not principle, Nobel Prizes have not been awarded. This was, for example, for long the case with astrophysics, and appears to remain so with the earth and marine sciences and also with some biological sciences. It is therefore to compensate for this, as well as in recognition of its undoubted prestige, that we also take into account the Copley Medal.

[12]The Royal Medals date back to 1825. Up to 1964, two medals were awarded each year for 'the most important contributions made' within a period of not more than ten years, and not less than one year of the date of the award in the physical and the biological sciences respectively (Lange and Buyers 1955). In 1965, a third medal was introduced, to be awarded annually for contributions in the applied sciences. The Medals are awarded by the Sovereign on the recommendation of the Council of the Royal Society.

The Copley Medal has been awarded by the Royal Society – though, unlike the Royal Medal, with no national restrictions – since 1737 for 'outstanding achievements' in any area of scientific research, now alternating annually between the physical and mathematical sciences and the biological sciences. Within the Royal Society, the Copley Medal has always been regarded as the highest distinction that it could confer and as thus outranking the Royal Medal (MacLeod 1971; Bektas and Crosland 1992). As Macleod notes (1971: 98), Royals have, for the majority of recipients, been 'Copley substitutes'. In a review of Zuckerman's work, Peter Medawar, himself a Nobel Laureate, has suggested (1977: 106) that the Copley Medal is in fact 'a rarer and, it can be argued, an even higher mark of distinction than the Nobel prize' – not least because, as well as being an international award, competition for it extends across all scientific fields.

As of 2020, which we take as our base year, the Fellows in UE1 number 127, or 6%, of all Fellows in our target population, while those in UE2 number 82, or less than 4% of our target population.[13] It may be noted that in UE1 there are 116 men and 11 women. Given that our target population of Fellows divides into 1957 men and 155 women, there is thus little difference between men and women in the proportions represented in UE1. However, of the 82 Fellows in UE2 only one is a woman, Dorothy Crowfoot Hodgkin, who won the Nobel Prize in Chemistry in 1964 (and the Copley Medal in 1976) although Jocelyn Burrell, here included in UE1 as a winner of the Royal Medal, did in 2021 – i.e. after our base year – also win the Copley Medal. We do not, on the basis of our present research, have data that would be relevant to accounting for this gender difference.[14]

Social characteristics of the elite and of the two possible ultra-elites

Our main concern is with how far the members of our two possible ultra-elites differ in various social characteristics from the other Fellows of the Royal Society included in our target population.

We begin by examining how far differences exist in social class origins. We determine Fellows' class origins by reference to their parents' class at the time of the Fellow's adolescence, ideally around age 15–16. We apply

[13]Of these 82, 35 (43%) also won the Royal Medal, in most cases before winning one of the international awards we consider.

[14]Why Burrell was not awarded a Nobel Prize, for her discovery of pulsars has been much discussed, and likewise why Rosalind Franklin did not receive greater recognition for her part in the discovery of the structure of DNA. But what, if any, general conclusions can be drawn from these two – very different – cases is unclear.

Table 1. Modified version of National Statistics Socio-Economic Classification (NS-SEC).

NS-SEC	Modified version and labelling used
1 Higher managers, large employers[a] and higher professionals	Higher professional[b]; Higher managerial[b]
2 Lower managers, higher supervisors and lower professionals and higher technicians	Lower professional[b]; Lower managerial[b]
3 Intermediate, clerical, etc. employees	Intermediate
5 Lower supervisors and technicians	Intermediate
4 Small employers and own account workers	Self-employed
6 Semi-routine workers	Working class
7 Routine workers	Working class

[a]With more than 25 employees.
[b]We follow here the NS-SEC distinction between Class 1.2 and 1.1 and make a similar distinction within Class 2.

a modified version of the UK National Statistics Socio-Economic Classification (Office of National Statistics 2005) as shown in Table 1.[15]

Previous research (Bukodi *et al.* 2022) has shown that while members of the UK scientific elite, as represented by Fellows of the Royal Society, tend to have relatively advantaged social class backgrounds, they are clearly more likely to come from professional than from managerial families and, increasingly, from higher professional families in which at least one parent is in an occupation involving some degree of scientific, technical, engineering or mathematical (STEM) knowledge and expertise. These findings are clearly reflected in Figure 1. However, our focus here is on how far differences arise in class origins as between Fellows who are members of the two ultra-elites we distinguish and the rest. Overall, what emerges is that while differences between Fellows in UE1 and the rest are neither large nor very systematic, Fellows in UE2 do appear in certain respects distinctive. Two-fifths are of higher professional origins – with more than half of this

[15]Where we have information – i.e. on occupation and employment status – that allow us to establish the class positions of a Fellow's father and mother, and these differ, we apply the 'dominance' method (Erikson 1984). In fact, given the historical period covered, many mothers were not in employment and those who were typically held class positions that were at a lower hierarchical level within NS-SEC than those of their husbands. Thus, in effect, parental class does in the very large majority of cases refer to father's class.

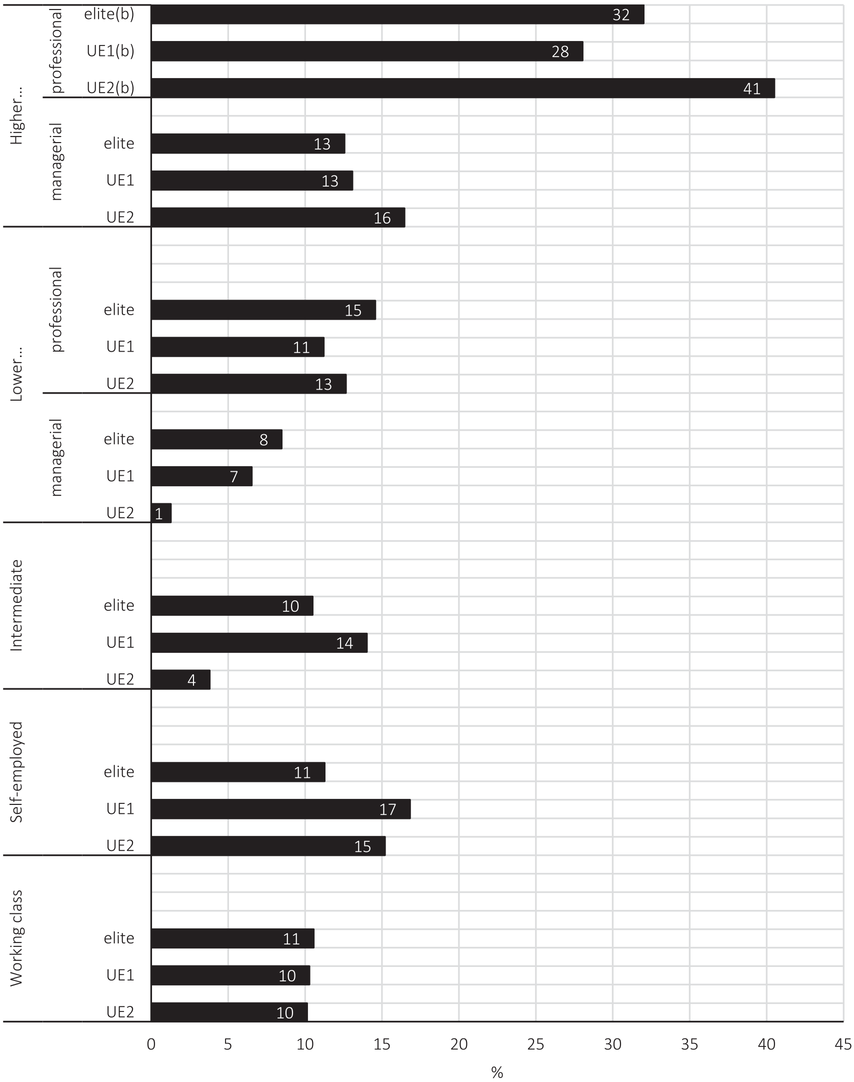

Figure 1. Proportion (%) of Fellows of different class origins in elite and in UE1 and UE2[(a)].

Notes: (a) Elite, $N = 1543$; UE1, $N = 107$; UE2, $N = 79$. (b) Proportion of Fellows coming from higher professional STEM families are as follows: UE2: 24%; UE1: 16%; elite: 19%

number coming from STEM families – while only around a third of Fellows in UE1 or the rest are of such origins.[16] Put differently, the chances of a Fellow in UE2 having come from a higher professional rather than any other background are almost twice those of a Fellow in UE1. The main

[16]The three most common occupations of the fathers of Fellows in UE2 are scientist (12 cases), engineer (7) and medical practitioner (6).

offsetting factor is then the small proportion of Fellows in UE2 who come from lower managerial and intermediate class families.

We turn next to secondary schooling. We know from our earlier work (Bukodi *et al.* 2022) that a high proportion of Fellows, upwards of two-fifths, had attended private schools, about the same proportion in fact as had attended state schools, with the remainder having their secondary schooling abroad. How far there are differences in these respects between Fellows in our two ultra-elites and other Fellows can be seen from Figure 2.

Again, it is Fellows in UE2 who are distinctive. Almost half of them attended private schools, as compared with a little over a third of Fellows in UE1 or other Fellows – with much of the difference arising from the proportion who went to Clarendon schools.[17] Fellows in UE2 were also more likely than others to have had their secondary education abroad. Offsetting these differences are then those in attendance at state grammar or comprehensive schools or other schools. Less than a third of Fellows in UE2 went to such schools as compared with a half of other Fellows. If we calculate the relevant odds ratio from the data of Figure 2, we find that the chances of a Fellow in UE2 being privately educated rather than not are more than twice those of a Fellow in UE1 or of other Fellows.

Finally, we come to university education at both undergraduate and postgraduate levels. A major finding from earlier work (Bukodi *et al.* 2023) is that Cambridge is clearly a more important source of the UK scientific elite, as represented by Fellows of the Royal Society, than any other British university, including Oxford. This finding then underlies Figure 3 relating to undergraduate education. But what emerges of relevance for our present concerns is the higher proportion of Fellows in UE2 who were Cambridge undergraduates – almost two-fifths, as compared with less than a third of Fellows in UE1 or of the rest. Fellows in UE2 were also more likely than others to have had their undergraduate education abroad. Offsetting differences then come with fewer members of UE2 having been undergraduates at London and fewer still – less than a fifth – at all UK universities falling outside of the Cambridge-Oxford-London ‘golden triangle’. The relevant odds ratio indicates that the chances of a Fellow in UE2 being a Cambridge undergraduate rather than not are more than twice those of a Fellow in UE1 and other Fellows.

[17]The Clarendon Schools are the nine ‘public schools’ whose finances and management were investigated by the Clarendon Commission (1861–1864) on account of what was taken to be their national importance as the ‘chief nurseries’ for ‘every profession and career’ in the country. They are Charterhouse, Eton, Harrow, Merchant Taylors’, Rugby, St Paul’s, Shrewsbury, Westminster and Winchester.

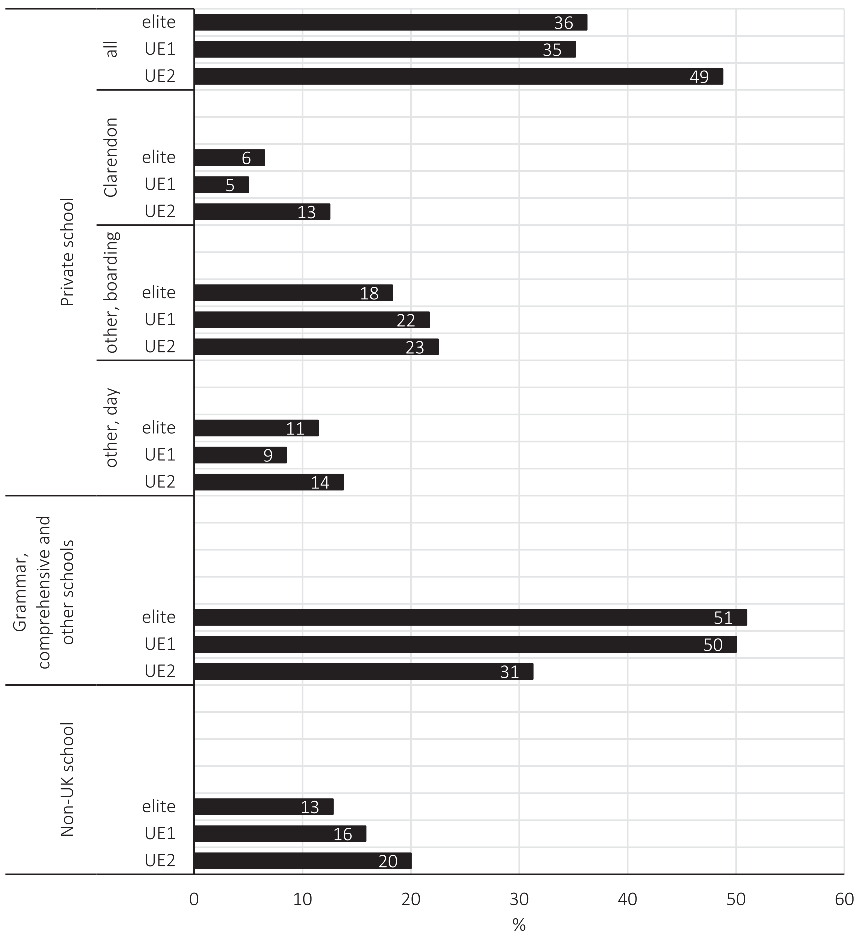

Figure 2. Proportion (%) of Fellows having attended different types of secondary school in elite and in UE1 and UE2[(a)].

Note: (a) Elite, $N = 1756$; UE1, $N = 120$; UE2, $N = 80$.

In moving on to postgraduate education, it can then be seen from Figure 4 that essentially the same pattern as with undergraduate education is present, except that as regards being a postgraduate at Cambridge, some clearer difference does now also show up between Fellows in UE1 and the rest. Still, the chances of a Fellow in UE2 being a Cambridge postgraduate rather than not are almost twice as great as those of a Fellow in UE1 and more than two-and-a-half times greater than those of other Fellows.

There are then clear indications that in the formation of UE2 at least, increasing social stratification is involved in comparison with UE1 and

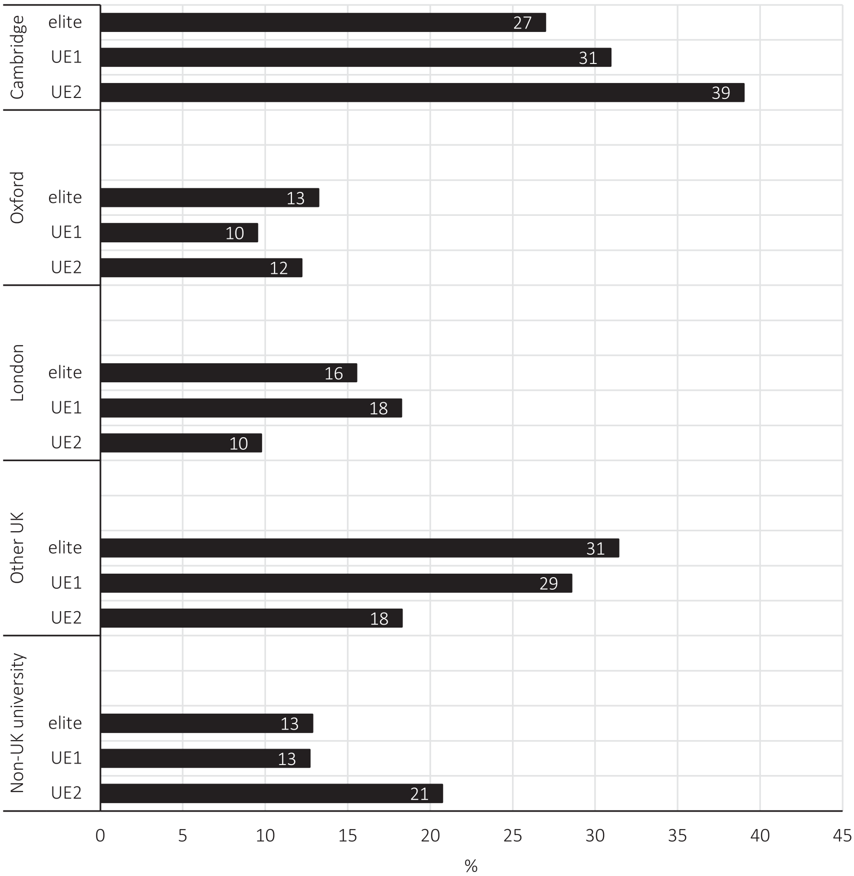

Figure 3. Proportion (%) of Fellows having attended different universities at undergraduate level in elite and in UE1 and UE2[(a)].
Note: (a) Elite, $N = 1908$; UE1, $N = 127$; UE2, $N = 82$.

other Fellows. The question may be raised of how far differences of the kind we have shown are persistent over time. The relatively small numbers in UE2 make reliable estimates difficult but on the basis of comparisons between two broad cohorts of Fellows, born 1900–1929 and from 1930 onwards, there are no indications of the social distinctiveness of those in UE2 substantially weakening (see Appendices 4–7).

However, to gain greater insight into the foregoing, we need to know more about how different aspects of stratification are interrelated. To this end, we necessarily have to simplify. We create four binary variables: for class origins, NS-SEC Class 1, that of higher professionals and managers, versus all others; for secondary schooling, private versus state; and for both undergraduate and postgraduate education, Cambridge versus all

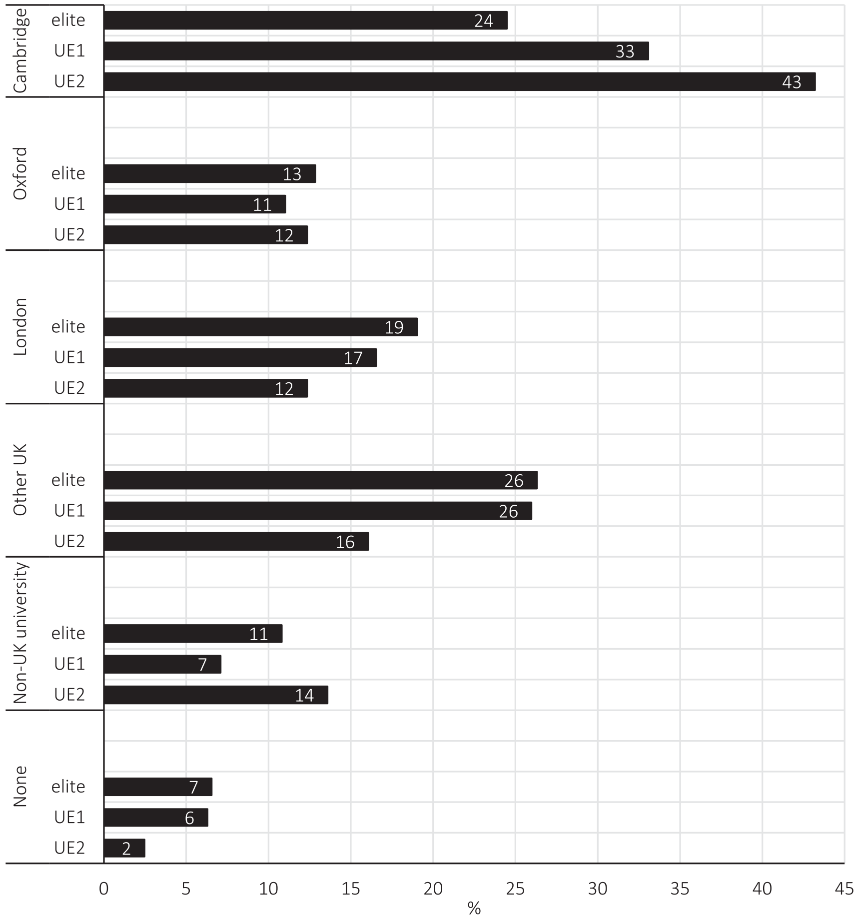

Figure 4. Proportion (%) of Fellows having attended different universities at postgraduate level in elite and in UE1 and UE2[(a)].

Note: (a) Elite, $N = 1908$; UE1, $N = 127$; UE2, $N = 82$.

other universities. We then run a binomial logit model from which we can derive estimated probabilities of Fellows of the Royal Society in the 16 groupings thus created being found in UE1 or in UE2. The results are shown in Figure 5.

What emerges most prominently from Figure 5 is the importance to ultra-elite access of having been at Cambridge and especially as a postgraduate. In the case of UE1, the four groupings with the highest probabilities of being members – 8–9% – all comprise Fellows who were at Cambridge as both undergraduates and postgraduates, regardless of their class origins and type of schooling. And the four groupings with the next highest probabilities – 6–7% – all comprise Fellows who

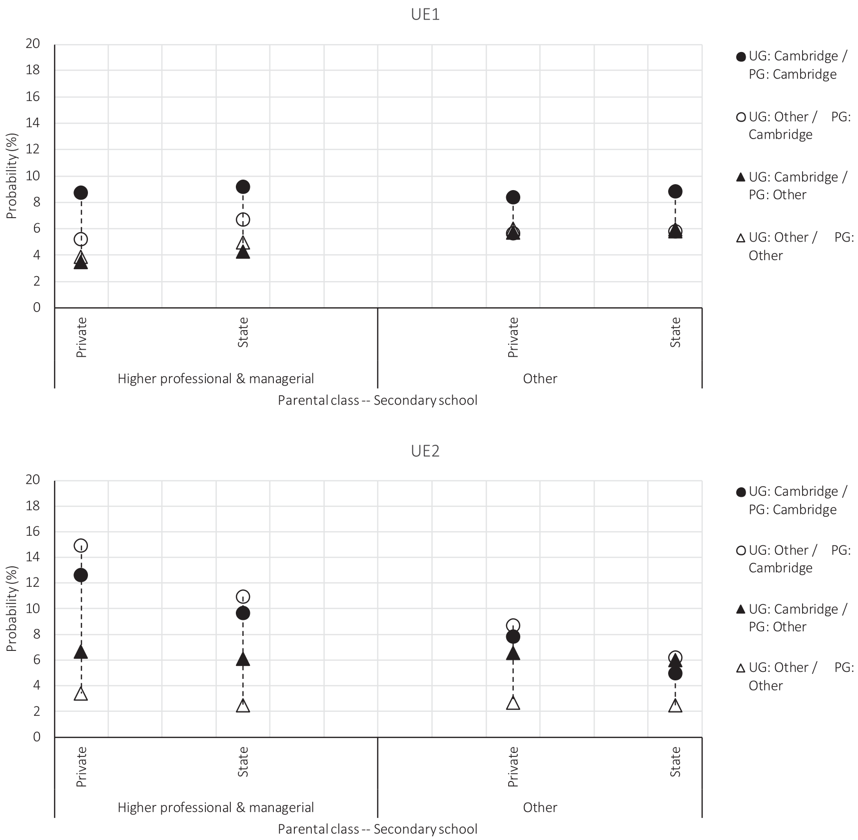

Figure 5. Estimated probabilities (%) of Fellows being found in UE1 and UE2 by parental class, type of secondary school and undergraduate (UG) and postgraduate (PG) university[(a)].

Note: (a) Based on a binomial logit model that includes parental class (dummy), type of secondary school (dummy), undergraduate university (dummy), postgraduate university (dummy) and interactions between these variables, with birth cohort (1900–1929 = 0, 1930– = 1) and field of research (math and physical sciences = 1, chemistry = 2, biochemistry = 3, other biological sciences = 4) as controls. Fellows who attended non-UK secondary schools and/or non-UK universities are excluded. *N* = 1290.

were Cambridge postgraduates, regardless of their social origins and type of schooling and of the fact that they were not Cambridge undergraduates.[18] In other words, insofar as social origins and type of schooling do have effects on the probability of Fellows becoming members of UE1, it would seem that these operate essentially via their university education – i.e. through having increased their chances of getting to Cambridge.

[18]It is also of interest that the four groupings with the lowest probabilities of being members of UE1 all comprise Fellows of Class 1 origins who, whether privately or state schooled, and whether undergraduates at Cambridge or not, did *not* become Cambridge postgraduates. Some process of negative selection may here be indicated.

However, with UE2 its distinctiveness once again emerges. The six groupings with the highest probabilities of being members – 8% or upwards – do all comprise Fellows who were Cambridge postgraduates *but now class origins and schooling also matter.* Across the groupings of Fellows who were Cambridge postgraduates, those from Class 1 families always have better chances of being found in UE2 than do those of less advantaged origins, as also do those who were privately rather than state schooled (though the differences here among those not of Class 1 origins are small). It can thus be seen that among our elite scientists those who were Cambridge postgraduates, came from Class 1 families and went to private schools have around 14% probability of being found in UE2, while those who were also Cambridge postgraduates but who were of other class origins and went to state schools have only a 6% probability.[19]

In sum, what emerges from the foregoing is that the way in which an ultra-elite is defined – how demanding the criteria for inclusion are – *is* of importance. Members of UE1, winners of the Royal Medal but who have not received any of the international awards we consider, are not clearly set apart in their class origins and their educational careers from other members of the UK scientific elite. But members of UE2, winners of Nobel prizes or of other international awards of comparable standing, do so differ in a clearly patterned way and to a non-negligible degree. They are more likely to come from more advantaged class backgrounds, to have been privately schooled, and to have attended Cambridge rather than any other UK university. It is no doubt the case that the line drawn between those who do and do not win awards is in some degree arbitrary as regards their scientific achievements. As Zuckerman and Crawford in effect agree, there will always be 41st chairs. Nonetheless, our findings suggest that in the case of a more stringently defined scientific ultra-elite, there is some clearer *social* differentiation from the body of other elite scientists than the ‘gradual fading’ of the one into the other that Crawford would claim.

The process of social stratification

We find evidence of social stratification in the formation of the scientific ultra-elite that we have defined in terms of its members’ having received

[19]The two groupings with the lowest probabilities of being members of UE2, again as with UE1, comprise Fellows of Class 1 origins, but in this case the two groupings in question are those who, whether privately or state educated, did not attend Cambridge at undergraduate *or* postgraduate level.

Nobel prizes or other international awards of comparable standard. We have also gained some understanding of the nature of this stratification. The question that then arises is that of how the stratification of this ultra-elite actually comes about. How does it occur that processes of making distinguished awards, based in principle essentially on judgements of individual achievement in science, should be associated with social stratification? And, more specifically, how far are the underlying mechanisms that Zuckerman identifies in this regard in the case of American Nobelists also evident in the formation of the ultra-elite in the UK?

One possibility is that decisions on the awards that we take as defining ultra-elite status are to some extent *directly* influenced by candidates' social characteristics as well as by the quality of their scientific work. While it is difficult to rule out this possibility entirely, we doubt if it could account for the degree of stratification that is in evidence. Apart from anything else, there is little reason to suppose that those charged with making international awards of the kind in question do have detailed knowledge of the social backgrounds of the individuals whose names come before them. Our focus is, rather, following Zuckerman, on processes that can lead to stratification among those scientists who emerge as the leading candidates for the most prestigious awards – which may then be made in ways subject primarily to the kinds of influence studied by Crawford and that in any event have to result in the drawing of lines through continua.

In what follows, we seek to examine, through detailed documentary-based analyses, how far Zuckerman's account of stratification in the US, as occurring through the mechanism of bilateral associative selection, can be extended to the UK. Zuckerman notes that in the US the operation of this mechanism is linked to a 'convergence' of leading scientific masters and their talented apprentices in a limited number of institutions – notably, Ivy League Columbia, Harvard and Yale together with Berkeley and MIT. In the UK, there is just one university where such ultra-elite convergence has been recurrent: that is, Cambridge. As an indication of Cambridge's scientific pre-eminence, it can claim 118 Nobel Prizes since their inception in 1904 – more than any other university except Harvard. It is, therefore, on Cambridge that we focus.

The initial instance of convergence at Cambridge is provided by the Cavendish Physics Laboratory, with its links to Trinity College, under the leadership of J. J. Thomson and then Ernest Rutherford. These masters, as well as being Nobel laureates themselves, played a significant role in the training of 17 others who won Nobel Prizes in Physics or in Chemistry in the earlier twentieth century (see further Rayleigh 1942;

Annan 1999: ch. 7; Cathcart 2005). However, we take up two later Cambridge cases. The first is that associated with the Cambridge Physiology Department, again with strong links to Trinity College and also, outside of Cambridge, to University College London. The second is that of the Medical Research Council's Laboratory of Molecular Biology, which had its origins in the Cavendish. The former is a relatively small case with clear 'traditional' elements, in which it is important to consider family and kinship networks as well as those among the scientists themselves. At its prime, it only partially overlaps with the period to which our prosopographical data relate. But in taking it together with the latter, clearly more 'modern', case we can – with Crawford's critique of Zuckerman's 'ahistorical' approach in mind – extend our analyses over a period of significant institutional and wider social change.[20]

The Cambridge physiologists

The individuals listed in Table 2 do not relate to the Physiology Department itself but rather can be taking as constituting the main scientific element within what Annan (1955, 1999: ch. 7) has characterised as the British 'intellectual aristocracy' that formed in the late Victorian era. This aristocracy emerged out of the growing numbers of men from relatively advantaged, mainly professional, class backgrounds who had a university education, and was consolidated through extensive intermarriage among a number of leading families. In the case in question, three such families, the Darwins, the Keynes and the Huxleys crucially came together.

If, for some individuals, we extend our criteria back in time, eight of the 21 men in Table 2 would count as members of UE2, all but one of whom – George Howard Darwin – worked in physiology or related fields. Also included are another seven who would count as elite scientists in being Fellows of the Royal Society, plus one other who became a Cambridge professor. Table 2 also indicates that of the total of 21 men listed, 14 were the sons of others listed and that in seven of these cases father and son were alike scientists.[21] Three of the others were the sons of

[20]Our primary biographical sources in the first case study are the Royal Society *Biographical Memoirs* and the *Dictionary of National Biography*. In the second case study, we mainly rely on published biographical notes, biographies and autobiographies as well as on historical works, all of which are appropriately referenced.

[21]Alan Hodgkin's father studied Natural Sciences at Trinity and became a friend of another leading physiologist of the time, Keith Lucas, FRS. He hoped to qualify as a doctor and to go on to physiological research but bad eyesight forced him to change career and move into banking.

Table 2. The Cambridge physiologists, forerunners and associates.

			Research field/occupation (institution)	Awards	Father/Father's occupation	School	Under- and postgraduate university
Charles Darwin	(1809–1892)	FRS	Biology (private)	Royal, Copley	Medical doctor	Shrewsbury (private, Clarendon)	Edinburgh; Cambridge (Christ's)
Thomas Henry Huxley	(1825–1895)	FRS	Biology, anatomy (London)	Royal, Copley	Mathematics teacher	Ealing School (private)	Charing Cross Hospital
George Howard Darwin	(1845–1912)	FRS	Geophysics (Cambridge)	Royal, Copley	Charles Darwin	Clapham School (private)	Cambridge (Trinity)
John Neville Keynes	(1852–1949)		Moral sciences (Cambridge)		Floriculturist	Amersham Hall (private)	UCL; Cambridge (Pembroke)
Leonard Huxley	(1860–1933)		Biographer and science writer		Thomas Henry Huxley	University College School, London (private)	St. Andrews; Oxford (Balliol)
John Maynard Keynes	(1883–1946)		Economics (Cambridge)		John Neville Keynes	Eton (private, Clarendon)	Cambridge (King's)
Archibald Vivian Hill	(1886–1977)	FRS	Physiology (UCL)	Royal, Copley, Nobel	Timber merchant	Blundell's School (private)	Cambridge (Trinity)
Charles Galton Darwin	(1887–1962)	FRS	Physics (Edinburgh)	Royal	George Howard Darwin	Marlborough (private)	Cambridge (Trinity)
Julian Huxley	(1887–1975)	FRS	Zoology (Royal Institution, London)		Leonard Huxley	Eton (private, Clarendon)	Oxford (Balliol)
Edgar Adrian	(1889–1977)	FRS	Physiology (Cambridge)	Royal, Copley, Nobel	Civil servant	Westminster (private, Clarendon)	Cambridge (Trinity)

Geoffrey Keynes	(1889–1982)		Surgeon		John Neville Keynes	Rugby (private, Clarendon)	Cambridge (Pembroke)
Aldous Huxley	(1894–1963)		Novelist, philosopher		Leonard Huxley	Eton (private, Clarendon)	Oxford (Balliol)
Bernard Katz	(1911–2003)	FRS	Physiology, biophysics (UCL)	Copley, Nobel	Fur trader	König Albert Gymnasium, Leipzig	Leipzig; UCL
Alan Hodgkin	(1914–1998)	FRS	Physiology (Cambridge)	Royal, Copley, Nobel	Bank official	Gresham's School (private)	Cambridge (Trinity)
David Keynes Hill	(1915–2002)	FRS	Physiology (Cambridge)		Archibald Vivian Hill	Highgate School (private)	Cambridge (Trinity)
Andrew Huxley	(1917–2012)	FRS	Physiology (UCL, Cambridge)	Copley, Nobel	Leonard Huxley	Westminster (private, Clarendon)	Cambridge (Trinity)
Maurice Neville Hill	(1919–1966)	FRS	Oceanography (Cambridge)		Archibald Vivian Hill	Highgate School (private)	Cambridge (King's)
Richard Darwin Keynes	(1919–2010)	FRS	Physiology (Cambridge)		Geoffrey Keynes	Oundle School (private)	Cambridge (Trinity)
Richard Hume Adrian	(1927–1995)	FRS	Physiology (Cambridge)		Edgar Adrian	Westminster (private, Clarendon)	Cambridge (Trinity); UCL
Jonathan Alan Hodgkin	(1949–)	FRS	Genetics (Oxford)		Alan Hodgkin	Bryanston (private)	Oxford (Merton); Cambridge (Darwin)
Roger John Keynes	(1951–)		Physiology (Cambridge)		Richard Darwin Keynes	Leys School (private)	Cambridge (Trinity)

medical practitioners and all but two of the remainder likewise came from professional families – the exceptions being Archibald Vivian Hill and Bernard Katz, whose fathers were merchants. Table 2 then further shows that, apart from Katz, all were privately educated, eight at Clarendon schools, and that 15 were at some point students at Cambridge, with 10 being graduates and/or Fellows of Trinity. Edgar Adrian, Alan Hodgkin and Andrew Huxley all became Masters of Trinity.

In Figure 6, relations existing among these 21 men through descent and marriage as well as through being scientific masters, apprentices and collaborators, are traced out. Other relations as, for example, of close friendship also existed but are not here included. In the linking of the Darwins, Keynes and Huxleys, Hill and Edgar Adrian, though not themselves of these families, can be seen to play a central role. Hill and Adrian were contemporaries in the Cambridge Physiological Laboratory in the years before World War I, developing a tradition of research into nerve impulses and muscular contraction. After the war, Hill moved on, eventually to UCL, while always maintaining his close Cambridge ties, while Adrian remained in Cambridge throughout his life. They received their Nobel prizes in Physiology or Medicine in 1922 and 1932 respectively.

The Keynes, as can be seen, first became joined with the Darwins through the marriage of John Neville Keynes' son, Geoffrey Keynes, to George Howard Darwin's daughter, Margaret, and Hill then came into this connection through his marriage to John Neville Keynes' daughter, also Margaret. Adrian became in turn linked to the Keynes through the marriage of his daughter, Anne, to Richard Darwin Keynes, the son of Geoffrey and Margaret Keynes. The connection between Adrian and the Huxleys came about more indirectly and through work rather than marriage. Andrew Huxley was the grandson of Thomas Henry Huxley, 'Darwin's bulldog', whom he greatly revered.[22] At Trinity, he was a student of Alan Hodgkin, a former student of Adrian, and then became Hodgkin's collaborator. He married Richenda Pease, a descendant of Charles Darwin. Hodgkin and Huxley's research, much in the Hill-Adrian tradition, led to them sharing the Nobel Prize in Physiology or Medicine in 1963, and they subsequently collaborated with Katz, one of Hill's students, who won this prize in 1970. Hodgkin went on to work with Adrian's son, Richard Hume Adrian and to complete the circle, as it

[22]He once remarked that his own work directly reflected his grandfather's recognition of the importance of 'the mechanical engineering of living machines'.

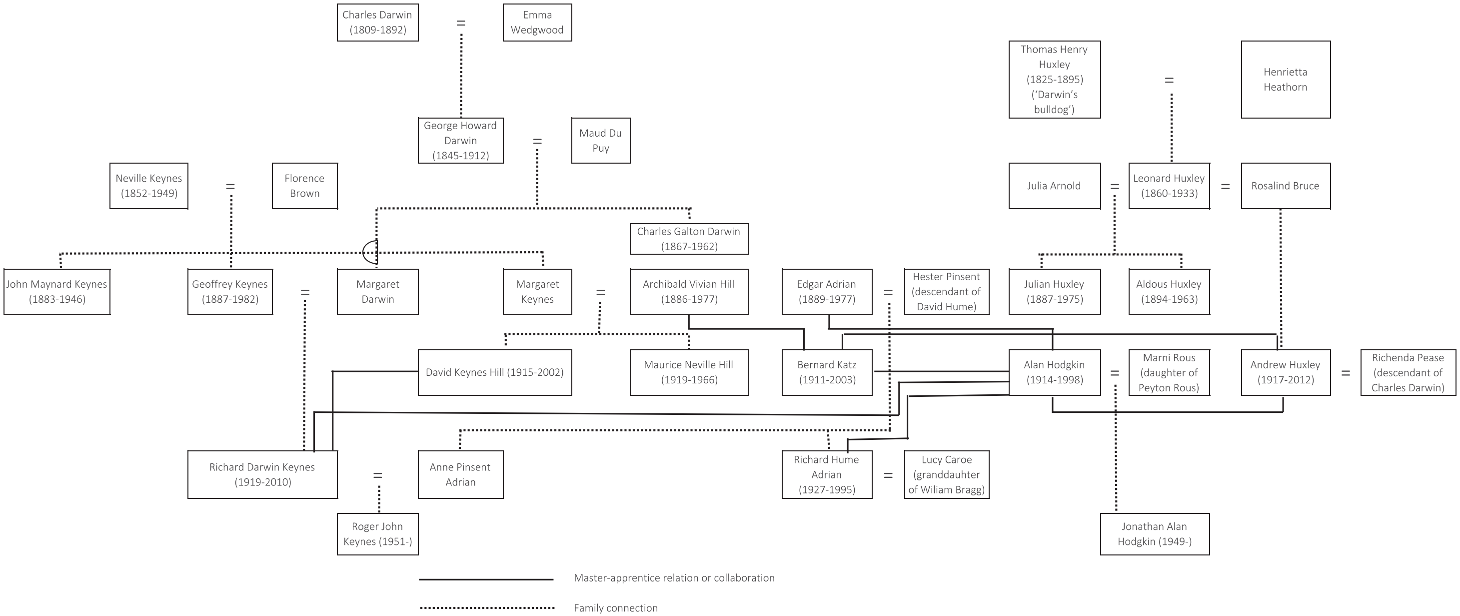

Figure 6. The Cambridge physiologists: family connections and master-apprentice relations or collaborations.

were, also with Richard Darwin Keynes. For the next generation, it can be seen that the latter's marriage to Anne Adrian produced Roger John Keynes, who became Professor of Physiology at Cambridge; and Hodgkin's marriage to Marni Rous, the daughter of Francis Peyton Rous, an American physiologist who was also a Nobelist, produced Jonathan Hodgkin, who became Professor of Genetics at Oxford and a Fellow of the Royal Society.[23]

Can we then see, in this context, the operation of the processes through which, according to Zuckerman, stratification is brought about in the formation of a scientific ultra-elite? It can in fact be said that the case of the Cambridge physiologists serves to reveal these processes at work in every respect and in a rather extreme form.

The men within the scientific component of the intellectual aristocracy that we have identified who themselves became scientists not only sprang from socially advantaged families but also received high quality schooling and then, in almost all cases, went to Cambridge, the leading British university for science, and were often members of Trinity, its scientifically most distinguished college. Further, a majority came from scientific families, and often ones in which some scientific eminence had been achieved in earlier generations. One can therefore suppose that, to use Zuckerman's phrases, many were from an early age 'socialized in the ways of science' and that as their scientific interests developed, were 'tuned in early to the major channels of communication about new developments' in their fields. And, as for access to possible masters with 'scientific talent of Nobel caliber', these were readily to hand in their own university or indeed within their own families and their social networks.

The one evident 'outsider' is Katz, who does, however, still provide a good example of the importance of the mutual search between masters and talented would-be apprentices. From his medical studies at Leipzig and some early research of his own, which had won him a prize, Katz knew of Hill's work, and in 1935 sought to leave Germany – he was of Jewish descent – in the hope of joining Hill at UCL. He had support from his physiology professor and also, and more importantly, an influential mediator in Chaim Weizmann, who had met Katz and also knew of Hill's concern to help German-Jewish scientists. On meeting the young Katz, Hill was impressed, provided him with a research post, and for a

[23]Andrew and Richenda Huxley had one son – who became director of a precision engineering firm – and five daughters who appear to have had no particular interest in science. Richard Hume Adrian married Lucy Caroe, a historical geographer and granddaughter of the physicist and Nobelist, William Bragg, but the marriage was childless.

time took him to live with his own family (see further on Katz, Stahnisch 2022).

Although almost all of the scientists included in Table 2 could, as Fellows of the Royal Society, be counted as among the scientific elite, not all achieved ultra-elite status as we have defined it. But what is here further illustrated is Zuckerman's argument that particular social contexts are conducive to a relatively large number of scientists becoming *at least potential members of the ultra-elite,* no matter how – perhaps in the ways emphasised by Crawford – the line is in the end drawn between those who do or do not become actual members. It is in this regard relevant to note that several of the scientists in Table 2 who, by our criteria, do not fall into the ultra-elite did nonetheless receive significant recognition of their scientific eminence and could very possibly have been nominated for Nobel Prizes or other awards, which, had they obtained them, would have given them ultra-elite status.[24]

The Cambridge molecular biologists

In 1947 Lawrence Bragg, who in 1915 had shared the Nobel Prize in Physics with his father, William Bragg, and had then succeeded Rutherford as Cavendish Professor of Physics at Cambridge, obtained financial support from the Medical Research Council to set up a Unit for the Study of the Molecular Structure of Biological Systems. This Unit, housed in the Cavendish Laboratory, initially comprised just two researchers: Max Perutz, an Austrian chemist who had arrived in Cambridge in 1936 to study with J. D. Bernal, and John Kendrew, a postgraduate, both working on the structure of proteins.[25] Another postgraduate, Hugh Huxley,[26] joined the Unit in 1948, supervised by Kendrew, and several more came in the next few years including Francis Crick, supervised by Perutz. James Watson arrived as a postdoctoral researcher in 1951. By 1957, the growing Unit had been forced out of the main Cavendish

[24]For example, Julian Huxley received the Darwin Medal of the Royal Society and the Darwin-Wallace Medal of the Linnaean Society, Maurice Hill the Chree Medal of the Physical Society, and Jonathan Alan Hodgkin the UK Genetics Society Medal and the Novitski Prize of the Genetics Society of America.

[25]Bernal, a pioneer of X-ray crystallography in molecular biology, was a classic example of an 'evoker of excellence' in Merton's sense. He left the Cavendish in 1937 to become Professor of Physics at Birkbeck College, London, but kept in close touch with Perutz, and in the course of wartime work, became an important influence on Kendrew too. He was also the mentor – and lover – of the eventual Nobelist, Dorothy Crowfoot, before her marriage to Thomas Hodgkin, a cousin of Alan Hodgkin (see Ferry 2007).

[26]Hugh Huxley had no connection with the Huxley family of Figure 6 but he did for a time collaborate with Andrew Huxley – one of several linkages that developed between the molecular biologists and the physiologists.

building into an adjacent prefabricated hut. However, in 1962 it moved into a new MRC funded building, and became the MRC Laboratory of Molecular Biology, headed by Perutz. Incorporated into it at this time were the Biochemistry Department's research group on proteins under Fred Sanger, already winner of the Nobel Prize in Chemistry, and Aaron Klug's virus group from Birkbeck. Further 'convergence' occurred when Perutz arranged for John Gurdon's cell biology group from the Department of Zoology at Oxford, which was also MRC funded, to transfer to the LMB. In 2013, the Laboratory moved again into a still larger building on the outskirts of Cambridge.[27]

In Table 3, we list the 19 men associated with the LMB who, following our criteria, gained ultra-elite status.[28] Of these, 17 are Nobelists in either Chemistry or Physiology or Medicine, while the two others, Huxley and Fersht, won both the Royal and the Copley medals and, as regards Nobels, could well be thought of as '41st chair' occupants. Huxley was certainly nominated for a Nobel by Perutz (Ferry 2007: 204). By the end of the twentieth century, the LMB had in fact gained an international reputation as a 'Nobel factory', where work focused on the central problems of a rapidly developing research field.

The ultra-elite scientists of the LMB differ from the Cambridge physiologists in several ways. First, reflecting the increasing globalisation of science, more are of foreign origin. As can be seen from Table 3, eight had their secondary schooling and perhaps some university education abroad, and then came to Cambridge not only as undergraduates or postgraduates but also as postdocs or already holders of faculty positions. Second, of those educated in the UK, not all, as with the physiologists, went to private schools – four were state school pupils – and a somewhat larger proportion were undergraduates at universities other than Cambridge. Third, while we cannot give full details, the molecular biologists do not come so uniformly from advantaged class backgrounds as did the physiologists. Among their fathers, we find a baker, a cobbler, a drover and a stonemason, and further only four of the 19 came from what could be regarded as scientific families.[29] What has, though, at the same time to be observed is that in the formation of this particular

[27]Finch (2008) provides a detailed history of the LMB up to 2006. We draw further on biographical and autobiographical accounts as cited.
[28]We include only those who were on the staff of the LMB for at least two years, rather than just visitors.
[29]It can be seen that in three cases we do not provide information on father's occupation. For two of these cases we have this information but do not report it since it comes not from sources in the public domain but from our online survey, respondents to which were given assurances of personal confidentiality.

Table 3. The Cambridge molecular biologists.

			Awards	Father's occupation[a]	School	Universities
Max Perutz	(1914–2002)	FRS	Royal, Copley, Nobel	Textile manufacturer	Theresianum Vienna	Vienna, Cambridge (Peterhouse)
Francis Crick	(1916–2004)	FRS	Royal, Copley, Nobel	Boot and shoe manufacturer	Mill Hill School (private)	UCL, Cambridge (Churchill)
John Kendrew	(1917–1997)	FRS	Royal, Nobel	Climatologist	Clifton College (private)	Cambridge (Trinity)
Fred Sanger	(1918–2013)	FRS	Copley, Nobel (2)	Medical practitioner	Bryanston (private)	Cambridge (St. John's)
Hugh Huxley	(1924–2013)	FRS	Royal, Copley	Sorting clerk and telegraphist	High Park School, Birkenhead	Cambridge (Christ's)
Aaron Klug	(1926–2018)	FRS	Copley, Nobel	Drover	Durban High School for Boys	Witwatersrand, Cambridge (Peterhouse)
Sydney Brenner	(1927–2019)	FRS	Royal, Copley, Nobel	Cobbler	Germiston High School, SA	Witwatersrand, Oxford (Exeter)
César Milstein	(1927–2002)	FRS	Copley, Nobel	Salesman	Colegio Nacional, Bahía Blanca	Buenos Aries, Cambridge (Darwin)
James Watson	(1928–)	FRS	Copley, Nobel	Businessman	South Shore High School, Chicago	Chicago, Indiana
John Gurdon	(1933–)	FRS	Royal, Copley, Nobel	Banker	Eton (private, Clarendon)	Oxford (Christ Church)
John Walker	(1941–)	FRS	Copley, Nobel	Stonemason	Raistrick Grammar School	Oxford (Merton)
John Sulston	(1942–2018)	FRS	Nobel	Army chaplain	Merchant Taylors' School (private, Clarendon)	Cambridge (Pembroke)
Alan Roy Fersht	(1943–)	FRS	Royal, Copley	Tailor	Sir George Monoux Grammar School	Cambridge (Caius)
Richard Henderson	(1945–)	FRS	Copley, Nobel	Baker	Boroughmuir High School	Edinburgh, Cambridge (Corpus)
Georges Köhler	(1946–1995)	FRS	Nobel	Not available	Kehl Gymnasium	Freiburg
Robert Horvitz	(1947–)	FRS	Nobel	Accountant	East Prairie Grammar Sschool, Chicago	MIT, Harvard
Michael Levitt	(1947–)	FRS	Nobel	Not available	Pretoria Boys High School	King's College London, Cambridge (Peterhouse)
Gregory Winter	(1951–)	FRS	Royal, Nobel	Not available	Royal Grammar School, Newcastle-upon-Tyne (private)	Cambridge (Trinity)
Venki Ramakrishnan	(1952–)	FRS	Copley, Nobel	Biochemist	Convent of Jesus and Mary, Baroda, India	Baroda, Ohio, California, San Diego

[a]Only when information is available in published sources.

ultra-elite stratification does still occur and on much the same lines as is more generally apparent with UE2, as reported above. Similar proportions of the molecular biologists as of other members of UE2 came from higher professional or managerial families, had, if living in the UK, private schooling, and attended Cambridge as undergraduates and/or postgraduates.

In Figure 7, we show connections between members of the LMB ultra-elite. As can be seen, in further contrast with the physiologists, relations through descent or marriage are absent. 'Convergence' did not in this case come about with the help of a network of family ties. The connections indicated are ones of supervision or mentoring and of collaboration. We do not distinguish between these, since the supervision and mentoring of apprentices by masters often merged with or led on to collaboration. From Figure 7, 'intergenerational filiations' are evident but also further research-based connections – and with, very probably, a number of omissions. Within the LMB, the exchange of ideas and expertise and informal collaboration were strongly encouraged. Perutz believed it was essential for close interaction to occur between researchers in the different divisions.[30] The canteen, run by Perutz's wife, Gisela, was the main locus of such interaction. Intensive discussions went on – always on first-name terms – over coffee, lunch and tea, and the canteen came in fact to be regarded as 'the intellectual centre of the Laboratory' (Ferry 2007: 198–201; see also Finch 2008: 275–9).

How far, then, in the case of the LMB, was a process of bilateral associative selection between leading scientists and talented and ambitious young researchers again in operation, and a source of the stratification of the ultra-elite? The available evidence indicates that this process did indeed continue. The LMB was a magnet for young researchers in molecular biology and related fields, while its staff were very ready to engage in talent-spotting and even head-hunting – although the process of mutual search in various respects differed from the way in which it had gone on with the physiologists.

Some young scientists did enter the LMB, and there achieve ultra-elite status, in what might be thought of as traditional style. Fersht went to a highly selective grammar school and Winter to a private school before going on to take their first degrees, with first-class honours,

[30]Initially, the LMB had three divisions: Protein Crystallography, headed by Kendrew; Protein Chemistry, headed by Sanger; and Molecular Genetics, headed by Crick. These were later broadened and renamed.

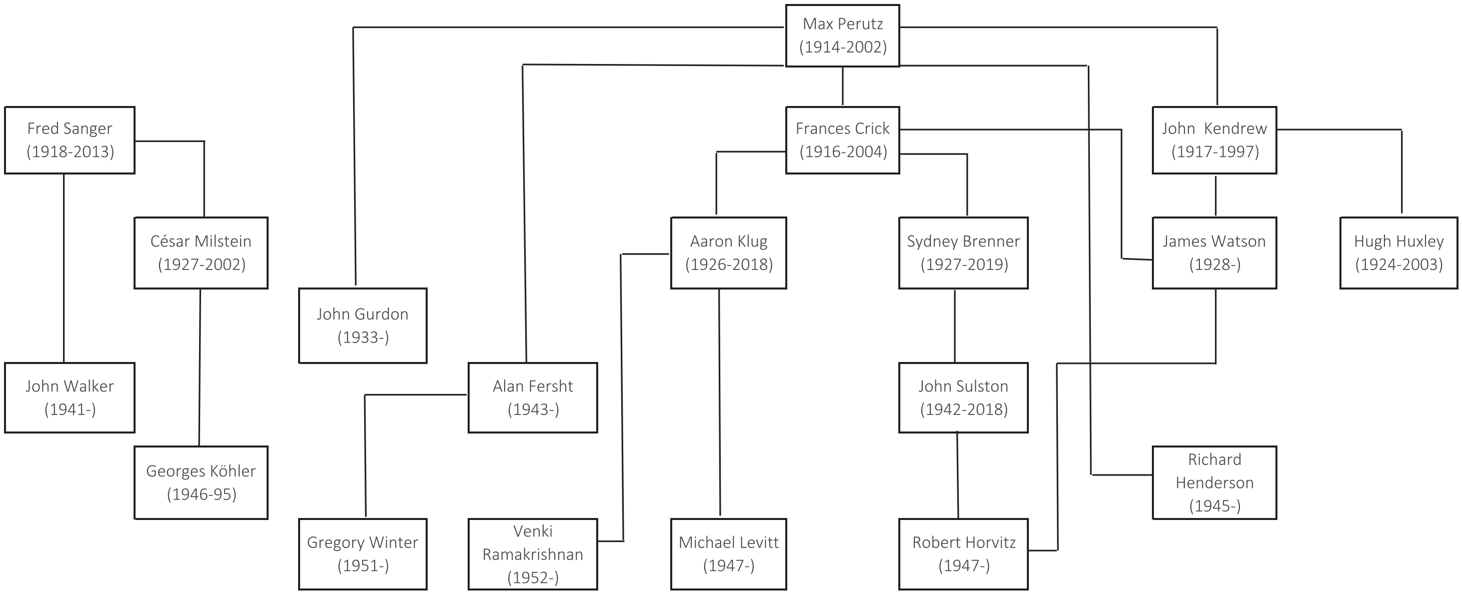

Figure 7. The Cambridge molecular biologists: master-apprentice relations and collaborations.

at Cambridge, and then found ready supervisors at the LMB for their doctorates – Fersht in fact supervising Winter.[31]

However, mutual search increasingly occurred on a national and a global rather than a local basis, though with Matthew effects still clearly in operation. Brenner, who had come from South Africa to take a doctorate in chemistry at Oxford, under the supervision of the Nobelist, Cyril Hinshelwood, was included in the Oxford party invited over to Cambridge in 1953 to see the final Crick–Watson model of the structure of DNA. Brenner was enthused and said he would be ready to work in a cupboard if he could come to the LMB. After Brenner had further meetings with Crick and Watson in the US, Crick agitated – successfully – for him to be recruited (Ferry 2007: 173–4; Brenner 2001). Milstein came from Argentina with the resources to take a second doctorate in the Biochemistry Department at Cambridge, where he began collaboration with Sanger. After a short period back in Argentina, he sought to return to Cambridge and was welcomed by Sanger as a member of his group, now at the LMB (Milstein 1984; Finch 2008: 230–1). Walker, another with a doctorate from Oxford but working at the Pasteur Institute in Paris, came to a conference in Cambridge where he met Sanger and, after a discussion, was also invited to join Sanger's group (Finch 2008: 225). Köhler, based in Freiburg, heard Milstein talk at a seminar in Basel, impressed him with some of his technical achievements, and was offered a LMB postdoc (Finch 2008: 233). And Ramakrishnan, having left India for a career in the US, took a sabbatical at the LMB – the only place he wanted to go to – and then, although having a professorship at Utah, aimed to get back to Cambridge and was eventually offered a position in Klug's group (Finch 2008: 159–60; Ramakrishnan 2009).

Further, what also increased in importance, and with a likely stratifying effect, was the role of mediators. Watson had studied with the Nobelist, Salvador Luria, and when Kendrew, on a visit to the US, told Luria that he was on the look-out for new talent to bring to Cambridge, Luria recommended Watson (Markel 2023: 147–8). Richard Henderson, who had taken a degree in physics at Edinburgh and wished to turn to biophysics, had a professor who was a friend of Perutz. An interview with Perutz and Kendrew was arranged, and Henderson was given a place as a doctoral student at the LMB – where he subsequently spent most of his career, eventually becoming Director (Henderson 2017).

[31]Fersht moved on to the US as a postdoc but was later persuaded to return to the LMB, while Winter stayed on as postdoc, staff member, Head of Division and Deputy-Director – and also became Master of Trinity.

Sulston, with a doctorate in chemistry from Cambridge, was a postdoc working with Leslie Orgel at the Salk Institute in California when Crick came as a visitor. Orgel, who knew Crick well, introduced Sulston to him and, after an interview with Crick, Sulston was offered a position at the LMB to work with Brenner (Sulston and Ferry 2003: 34–5). Horvitz, after majoring in maths at MIT, moved on to do graduate work in biology at Harvard, with Watson as an advisor. Watson wrote to Brenner recommending Horvitz for a postdoc slot at the LMB, and he too joined the Brenner group (Horvitz 2002).

It should not, though, be supposed that the process of mutual search always went as smoothly as the foregoing might suggest. And, where in the case of a young scientist difficulties arose, family economic advantage and social connections – associated perhaps with individual self-confidence – could help to get the process back on course. Crick, in seeking to move on from his training and wartime work in physics to do research on 'the borderline between the living and the nonliving' made a prospective visit to Bernal's laboratory at Birkbeck. Bernal was away but his secretary asked Crick 'Do you realise that people from all over the world want to come and work with the professor? Why do you think he would take you on?' (Crick 1988: 21), and Crick was in fact rejected. However, he had family money to tide him over until, with advice and support from two of the Cambridge physiologists, Hill and Richard Keynes, he joined the Strangeways Laboratory in Cambridge, where he spent two years learning some biology, before moving on to the Cavendish with Perutz (Crick 1988: 21–3). Levitt's application for a doctoral place at the LMB was initially turned down by Kendrew but then, after demanding an interview, he was told he might be accepted the following year but would have to wait and see. Levitt, who also came from a fairly wealthy family and was advised by an uncle who was a successful scientist, simply drove to Cambridge, found Perutz, and told him that he needed a decision on his application right away. After a discussion, Perutz said that he would be accepted in a year's time and, for the interim, funds were available for him to work at the Weizmann Institute in Israel (Levitt 2013).

We may then say that in the two cases, we have considered of the convergence in Cambridge of leading scientific masters and talented apprentices, the underlying process of bilateral associative selection that Zuckerman documents for the US is readily apparent. And so too is the way in which the formation of a body of at least potential ultra-elite scientists is thus associated with some degree of social stratification. The Cambridge physiologists represent a special case, in which the mutual search between masters and apprentices went on within a more or less closed social circle of distinguished families. The Cambridge molecular biologists are a case more representative of the present period, with both masters and apprentices coming from further afield geographically, being somewhat more diverse in their social origins and education, and without ties of kinship.

Nonetheless, the molecular biologists still show the same degree of social distinctiveness, relative to the scientific elite of Fellows of the Royal Society as a whole, as do the other members of our ultra-elite, UE2. In both of the cases that we have examined the same stratifying factors in the formation of an ultra-elite can in fact be identified. Advantaged class origins clearly help in getting into the process of selection early – and thus benefitting early from Matthew effects – through favourable schooling and university education, with reaching Cambridge as a postgraduate or post-doc, if not first as an undergraduate, being of particular importance. And family economic and social resources, along with influential academic connections, often too play a part in facilitating and mediating apprentices' search for, and their acceptance by, the masters most likely to promote their career ambitions.

Conclusions

In our study of the UK scientific ultra-elite, we have started out from Zuckerman's pioneering work on the US ultra-elite. This work we see as important in introducing into the analysis of social stratification in science the idea of Matthew effects – which has subsequently had much wider application – and, more generally, in illustrating the development of Mertonian middle-range theory in sociology so as to focus on the social processes underlying empirically demonstrable social phenomena. We also take up the controversy that arose between Zuckerman and Crawford, which, apart from its substantive interest, also reflects significant differences in emphasis between the explanatory efforts of sociologists and historians.

We have proceeded by identifying, within the UK scientific elite, as represented by Fellows of the Royal Society born since 1900, two possible ultra-elites in terms of awards received: one defined with reference to the winning of a nationally limited award, the other by reference to the winning of an international award – either a Nobel prize or an award of comparable standing – for which competition is obviously much stronger.

We have shown that with the first of these possible ultra-elites, UE1, little increase in social stratification is evident in comparing its members with the main body of Fellows of the Royal Society. However, this is not the case with the second ultra-elite, UE2. Members of UE2 are more likely than other Fellows to have higher professional parents and also ones in STEM occupations, to have been privately schooled, and to have attended Cambridge, the leading UK university for science. Further analysis then reveals the particular importance for access to UE1 and UE2 alike of being a postgraduate at Cambridge. But while with UE1 an advantaged class background and private schooling would appear mainly important insofar as they facilitate becoming a Cambridge postgraduate, with UE2 they are associated with increased chances of entering this ultra-elite even among Cambridge postgraduates.

To this extent, therefore, our findings are consistent with Zuckerman's view – while going contrary to that of Crawford – that social processes involving stratification lead to the formation of collectivities of scientists who can be regarded as in some degree socially distinctive and as being at least potential, if not actual, ultra-elite members. But where lines are ultimately drawn may well be significantly influenced by the deliberations, on which Crawford concentrates, of those charged with making the defining awards.

We move on next to the matter of how far, in the formation of collectivities of the kind in question, the bilateral associative selection occurring between leading scientific masters and their would-be apprentices, which Zuckerman sees as having been central in the US, is also in evidence in the UK. Following Zuckerman's observation that such selection is associated with a convergence of scientific talent in a limited number of centres, we consider two instances set in Cambridge, the one UK university in which such convergence is most evident.

The case of the Cambridge physiologists does in fact display the processes of ultra-elite formation suggested by Zuckerman in full and rather extreme operation, although in the context of a social world that no longer exists. However, also in the case of the Cambridge molecular biologists, covering the period up to the end of the twentieth century, we show that the search of scientific masters for apprentices and of apprentices for masters still goes on, and in ways that are associated with increased stratification. In short, our findings point to the fact that social processes of the kind that Zuckerman identified in the formation of the US scientific ultra-elite up to the late twentieth century are not place and time specific or at least not to the extent that Crawford would imply. Encouragingly for sociologists, these same processes can 'travel' – can be shown to be operative across quite different institutional and wider social settings.

We end with two qualifications.

First, while the two cases we have considered do in themselves account for over a quarter of all those falling into our more strictly defined scientific ultra-elite, we would not claim that mechanisms of the kind that Zuckerman and we have identified are universally involved in the formation of such ultra-elites and their stratification – only that they have to be seen as one generative process of some obvious importance. It is possible that they may operate on some smaller scale in cases where there is a less marked convergences of scientific talent than has recurrently occurred in Cambridge. But it is also possible that they are of less importance in some areas of scientific research than in others – as, say, where such research is not institutionalised in laboratories or field stations but carried out on a more individualistic basis, as in the case of mathematics.

Second, if in the formation of a scientific ultra-elite, some degree of social stratification does arise, as through the operation of Matthew effects of the kind we have illustrated, we would not see this as in any way detracting from the quality of the scientific work that leads to the awards by which ultra-elite status is defined. Nor would we see it as grounds for questioning the appropriateness of the procedures through which these awards are made. What is, however, indicated is that some undue restriction exists on the progression of highly talented scientists from the elite to an ultra-elite in the form of UE2. Even among scientists who become elite members, those from less advantaged class origins and with less privileged education do not appear to achieve career progression of the kind that leads to ultra-elite status to the same extent as do those more socially advantaged from the start. Unfortunately, far more biographical material is available to document the success stories of scientists of the greatest eminence than to bring out the difficulties that have possibly been encountered – in, say, securing access to leading masters and research centres – by those who fall short of such eminence. And it may further be the case that the differences in the cumulation of advantages over the course of scientific careers that arise from stratification by class and education are matched by those associated with gender and ethnicity.

The foregoing are matters on which further research into the formation of scientific elites and ultra-elites will need to focus.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The data underlying this article were collected by the authors. They will be placed in the public domain once the full project on British elites, of which this study forms part, is completed.

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Appendices

Appendix 1. Extent of coverage of target population of Fellows of the Royal Society by birth cohort

	Birth cohort							
	1900–1909	1910–1919	1920–1929	1930–1939	1940–1949	1950–1959	1960–	All
Initial target population (*N*)	278	251	373	321	366	319	204	2112
% of missing information on								
undergraduate studies	0.4	0.0	0.3	0.6	0.5	0.3	1.0	0.4
postgraduate studies	0.4	0.4	1.6	0.9	0.5	0.3	1.0	0.7
type of secondary school	2.5	1.6	2.4	6.9	7.7	16.6	20.6	7.8
parental class	2.9	6.0	16.4	24.9	23.0	24.8	29.4	18.3
Cumulative	5.0	7.2	18.5	26.5	24.9	27.6	32.4	20.4
Achieved target population								
N	264	233	304	236	275	231	138	1681
%	95.0	92.8	81.5	73.5	75.1	72.4	67.6	79.6

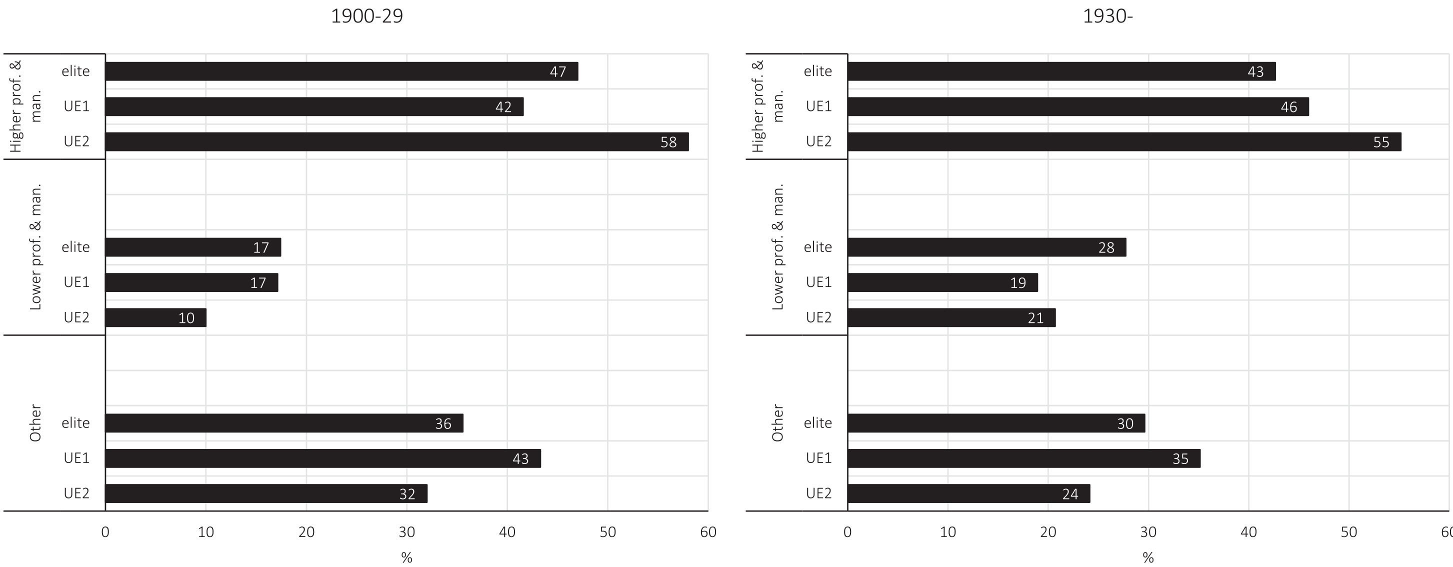
Appendix 2. Differences between living and deceased Fellows in estimated probabilities of coming from different class origins, average marginal effects (%) from a multinomial logit model

	Parental class				
	Higher professional	Higher managerial	Lower professional	Lower managerial	Other
Fellows living					
Yes (ref.)	0.0	0.0	0.0	0.0	0.0
No	0.9	−0.3	−1.4	−1.3	1.0
Cohort					
1900–1929	0.1	6.6	0.3	−6.0	−1.0
1930–1949 (ref.)	0.0	0.0	0.0	0.0	0.0
1950–	10.6	0.3	3.1	−0.1	−12.9

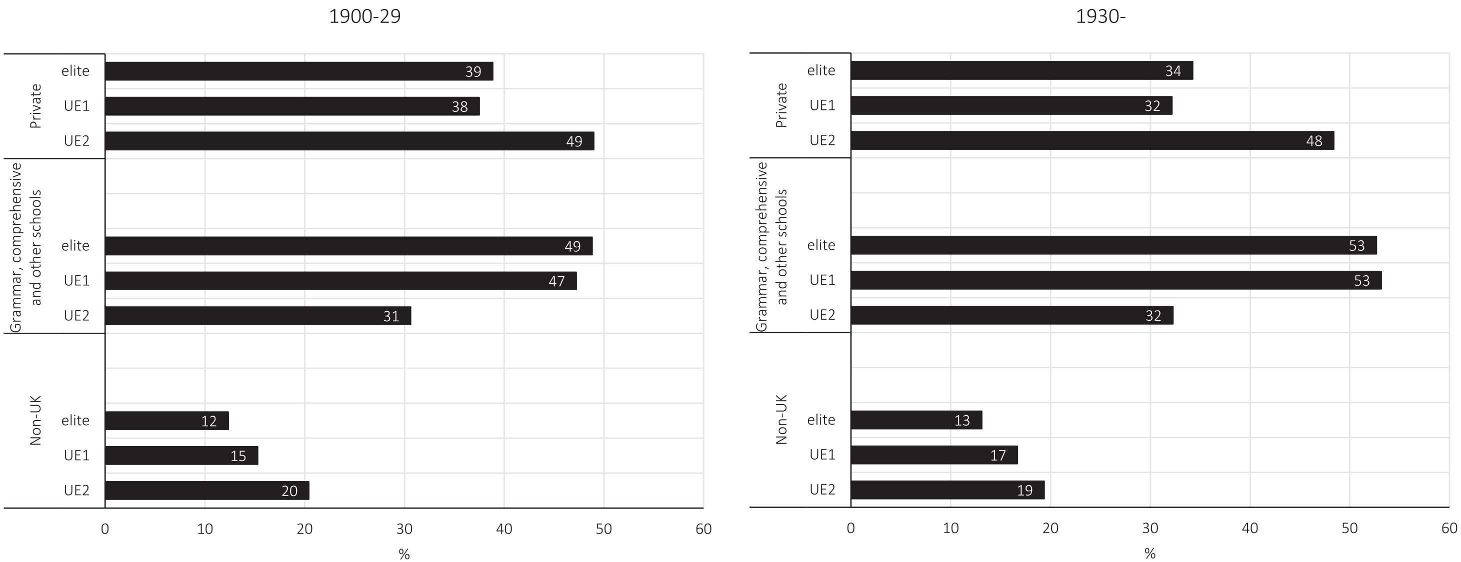
Appendix 3. Differences between living and deceased Fellows coming from different classes of origins in estimated probabilities of attending private rather than state secondary school, average marginal effects (%) from binomial logit models

	Model 1	Model 2
Fellows living		
Yes (ref.)	0.0	0.0
No	−2.1	−2.1
Parental class		
Higher professional (ref.)	0.0	0.0
Higher managerial	−3.7	−4.5
Lower professional	−29.2	−35.7
Lower managerial	−27.1	−33.9
Other	−46.5	−52.6
Parental class × Fellows living		
Higher professional (ref.)		0.0
Higher managerial		−1.6
Lower professional		3.7
Lower managerial		3.3
Other		2.6
Cohort		
1900–1929	1.0	2.2
1930–1949 (ref.)	0.0	0.0
1950–	−5.2	−5.0

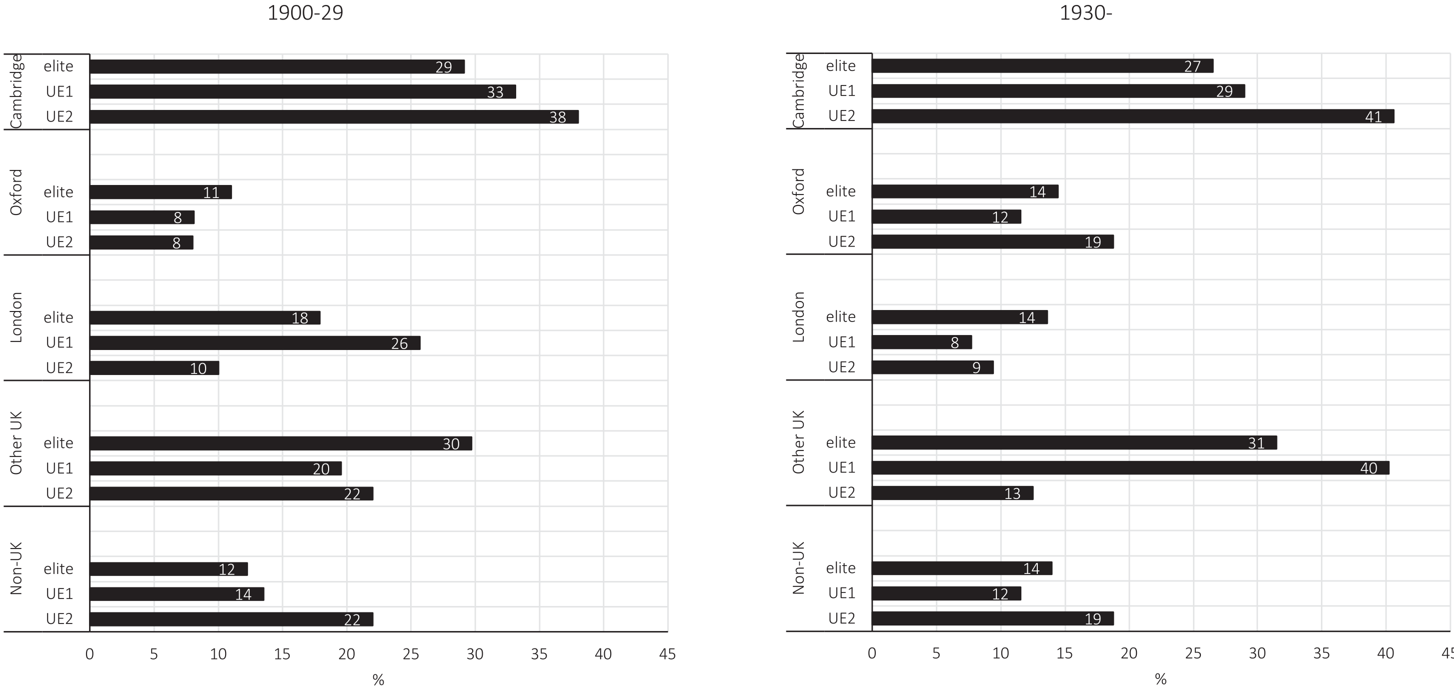
Appendix 4. Proportion (%) of Fellows of different class origins in elite and in UE1 and UE2, in two birth cohorts



Appendix 5. Proportion (%) of Fellows having attended different types of secondary school in elite and in UE1 and UE2, in two birth cohorts



Appendix 6. Proportion (%) of Fellows having attended different universities at undergraduate level in elite and in UE1 and UE2, in two birth cohorts



Appendix 7. Proportion (%) of Fellows having attended different universities at postgraduate level in elite and in UE1 and UE2, in two birth cohorts