The Effects of Size on Research Performance: A SPRU Review

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Executive Summary

i Opinions as to the relative merits of big or small units for carrying out research have varied over time, counterposing arguments for integration and breadth against those favouring specialisation, diversity and competition. In research, just as in production, there is a common if disputable presumption that larger units obtain ‘static economies of scale’ (disproportionately greater output – i.e. greater output per unit input) and ‘economies of scope’ (from the synergy derived from conducting several related activities in parallel). Set against this, smaller units may reap ‘dynamic’ economies of scale through greater agility and responsiveness to change.

ii Recent analyses of ‘knowledge production’ have suggested a trend from ‘Mode 1’ research (i.e. research conducted by individuals or teams often drawn from a single discipline and working within a single organisation) to ‘Mode 2’ research (i.e. research involving greater interaction between a widening range of knowledge producers in different disciplines, institutions, sectors and countries). This has been presumed by some to favour consolidation, but the logic of the argument is actually far more complicated.

iii Different forms of scale economies may arise according to the level of the unit of analysis on which one chooses to focus. This review has examined studies at the macro level of entire countries or regions, the meso level of institutions (e.g. universities) or their constituent departments, and the micro level of particular groups, teams or collaborations.

iv Measuring the output of the relevant unit is complicated for two main reasons: the diversity of ‘products’ created (e.g. teaching as well as research in the case of universities); and the need for the assessment to take account of the quality as well as the quantity of output. Bibliometric and other measures aim to adjust for quality in a variety of ways, all of which have considerable limitations in practice. The most promising approach involves the construction of multiple measures, as pursued in Data Envelopment Analysis (DEA) for instance, and this should be encouraged in future studies.

v The problem of the diverse range of ‘products’ is often tackled by adopting an econometric approach where the aim is to reduce the items to a common denominator. However, the various studies to date suffer from the usual econometric problem of oversimplifying causal relationships (‘simultaneity biases’) and from the uncertain form of the relationship between unit size and performance (‘specification errors’). Moreover, the very nature of ‘economies of scale’ or ‘economies of scope’ is riddled with conceptual ambiguities, for example as between static (size) and dynamic (flexibility) interpretations. In practice most studies have looked at the simple relationship between size (as opposed to 'scale') and output of research units.

vi In terms of research, the key unit would appear to be the group or team, rather than the department or the university (or institute). Such a team is typically focused around a relatively discrete subfield or research area (as opposed to a department which often spans an entire discipline). If the group is of a sufficient size (see below), the evidence suggests that it has the potential to carry out world-class research whether it is embedded in a small department of 15 or a large department of 50 faculty (and irrespective of the size of the university).

vii At this micro level where the unit of analysis is the group, team or perhaps the network, assessing 'average' outcomes is problematic because – as has long been known – the distribution of outputs across individuals and teams is highly skewed; consequently the presence of a 'star' can distort the average value. Nevertheless, there is reasonably convincing evidence of a size effect in the form a 'critical mass' threshold. In many scientific fields, productivity seems to rise as the team size increases to about six or eight persons, above which there is usually little or no extra gain per capita. Some studies find a lower 'threshold' beyond which additional economies do not arise, while a few (e.g. in arts and humanities) find no threshold at all. Where present, the threshold has been found to be somewhat higher in applied subjects such as clinical medicine, and it is probably lower in more theoretical subjects such as mathematics.

viii These results for teams are also pertinent to the 'meso' level of departments, since some studies find the 'optimal' size of departments to be some multiple of approximately eight or nine staff, suggesting that they are composed of several teams each of about optimal size. This then raises the question of economies of scope, of how many teams should constitute a department, but this appears to have been little investigated. Major studies for the UK by economists show little evidence of lower unit costs or higher efficiency with respect to research at the departmental level. Particularly small departments may indeed be inefficient, by analogy with small teams, but 'selection processes' may tend to drive such departments out of existence one way or another. In addition, several studies have identified distinct advantages as well as disadvantages of working in smaller departments.

ix Similar findings emerge from studies focusing on whole institutions. In general, there is no clear relationship between research productivity and university size. While some very small universities tend to be less productive in the USA (where the size range is far greater and the population more heterogeneous than in the UK), there are notable exceptions.

x Other variables affecting research performance almost inevitably intervene to complicate or upset any simple relationship between size and efficiency. The age structure, of both individuals and institutions, is often found to be relevant to research performance. Hence, if size tends to grow with the age of institutions, and if productivity falls with age of individuals, then larger units may actually be less productive. Organisational structures including management have frequently been considered to be relevant to research performance but the results appear to be rather specific to individual circumstances.

xi Few governments have actively pursued policies of concentrating research units. Japan is one exception, but the policy remains highly controversial, with little actual progress having been made. Countries differ in the overall degree of centralisation of their research structures and resources, but again the effects vary. Decentralisation is usually thought to be associated with increased competition, and hence perhaps with dynamic rather than static scale economies.

xii It has been claimed that the research performance of larger units and universities has improved faster in the UK since the mid-1980s. However, over the same period these have benefited from an increasing share of research funding. This finding therefore does not provide evidence about the presence or absence of economies of scale. In terms of productivity or output per unit input, there seems to be no evidence that larger departments or larger universities are more 'efficient' in their use of resources, perhaps even the reverse.

xiii Government policy towards university research has mostly tended to focus on the department (as in the Research Assessment Exercises). On occasions, the focus has been on the university as a whole (as in discussions in the 1980s of R, T and X universities[1], and more recently in moves to encourage institutional mergers and also the suggestion that resources should be concentrated on a small number of leading universities). Yet this review of the literature strongly indicates that the most important unit in relation to the organisation of research is the group or team rather than the department or institution.

xiv The evidence suggests that government policy to enhance performance across the national research system might be more effectively targeted at the micro level – for example, a policy aimed at encouraging increased interaction among smaller units to counteract the problem of 'loneliness' as opposed to 'smallness'.

xv In conclusion, there seems to be little if any convincing evidence to justify a government policy explicitly aimed at further concentration of research resources on large departments or large universities in the UK on the grounds of superior economic efficiency.

[1] R, T and X were the three types of universities envisaged in a report by the Advisory Board for the Research Councils (ABRC). R stood for 'research universities' (carrying out research across the broad spectrum of disciplines), T for 'teaching-only HE institutions' (i.e. doing little or no research), and X universities were those which only carried out research in a limited number of disciplines.

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A. Introduction

1. The issue of the relationship between the size of firms and their efficiency has been a central feature of industrial economics for many years – indeed, perhaps the most investigated of all questions in the field. For much of the 20th Century, there was a belief in the virtues of consolidation, in 'national champions' and the very 'visible hand' of corporate management. The advantages were seen as resting on 'economies of scale' (i.e. disproportionately greater output) and 'economies of scope' (i.e. synergies from harnessing allied activities). However, in the later years of the century, opinion in many countries swung back to favour small and medium-sized enterprises (SMEs), which were seen in some quarters as being more agile and responsive to change (related to the 'dynamic scale economies' discussed below). This shift partly reflected the acquisition of a deeper understanding of the underlying determinants of growth, including the declining relative importance of physical capital (plant and equipment) which weakened the previous argument for 'bigness', coupled with the growing importance of knowledge capital (e.g. human capital, R&D) which seemed to strengthen the argument for 'smallness'.

2. A parallel debate has long existed in relation to research, and the units responsible for the performance of research. As we shall see, the language, the concepts and indeed the methods have been transferred from industrial economics in order to assess the performance of universities and other research institutions. There are grounds for believing that research, too, is influenced by deeper driving forces which are altering the nature of the arguments. This change of view was highlighted by Gibbons et al. (1994), who argue that there had been a shift in balance from 'Mode 1' research conducted by individuals or teams often drawn from a single discipline and working within a single organisation, to 'Mode 2' research involving greater external connectedness among individuals and teams, who are also likely to come from a wider range of disciplines and organisations (see also Nowotny et al., 2001). 'External' here refers to both collaborations across disciplinary boundaries (i.e. growing multidisciplinarity) and those across organisational boundaries (including inter-sectoral and international collaborations). While the Mode 1/Mode 2 thesis and its various elaborations remain controversial, it has evident implications for any study of research performance according to size of unit. If 'knowledge production' (including research) is increasingly taking place through spanning boundaries (including international boundaries as fostered by EU Framework Programmes), what 'units' should we be studying? Are extensive networks

inherently superior? Not necessarily, since networks that are large and sprawling or 'bureaucratic' may not be very efficient. Where physical capital is critical, as in building a super-collider, there is clearly an argument in favour of physical consolidation, but even here this does not necessarily require a consolidation of human capital; a structure in which researchers are part of other institutions but share the use of the central facilities might be just as efficient.

B. Methodological Issues

3. Examination of recent literature on this subject, produced mainly over the last decade, reveals that the notion of 'size' has broadened considerably since a previous SPRU review of the subject in 1993 (Martin et al., 1993). While the size of research groups and academic departments remains a critical issue, several investigations have been directed at other organisational units from the individual researcher to whole universities and research institutes, research sectors and even regional or national scientific communities. This broader approach requires a much more complicated array of indicators, each with its own particular advantages and shortcomings.

B.1 Unit of Analysis

4. Studies such as those using bibliometric indicators have been carried out at all levels (van Raan, 2003). At the *macro* level are studies of whole regions or countries, providing much information on, for instance, the relative strength of country A in field x, but not in general with an associated breakdown to the level of individual research groups or programmes. (A rigorous cross-country correlation of relative national strength with relative predominance of bigger or smaller groups would be desirable but we are not aware of any such study – see the criticisms later of Adams et al., 2000.) For our purposes, many studies, especially those for the USA, take the *meso* level of analysis, examining larger institutions such as universities or research institutes, preferably disaggregated according to broad disciplinary area. The meso level has been the main focus of policy-makers in the UK over the last 20 years, with the selectivity exercises and Research Assessment Exercises (RAEs). It is also perhaps the easiest arena for policy intervention. However, the evidence suggests that the productivity of individual researchers is shaped mainly by the smaller (subfield-based) teams and collaborations with which they are most closely involved – i.e. at the *micro* level (Martin & Skea, 1992). The problem here is mainly one of obtaining relevant data, which is often lacking, or not comparable across institutions or confidential (ibid.). Even so, much research has gone into examining micro-level efficiency using approximate indicators based on publicly available sources, such as citation indexes. The kinds of economies of scale that

might be reaped differ according to the level of the analysis; for example, administrative benefits may be obtained at the meso but not the micro level.

5. One implication of the newer views on 'knowledge production' noted above is that a range of different sectors are increasingly involved in research (Katz & Hicks, 1996) – not just universities but also hospitals, other higher educational institutions, non-profit institutions, research councils, and not least industry, which is responsible for a surprisingly large share of total publications, including much basic research (Hicks, 1995). Institutions are becoming increasingly interlinked across sectoral boundaries.

B.2 Measurement of Inputs and Outputs

6. Any assessment of productivity or efficiency clearly has to relate outputs to inputs – one would expect larger departments to produce more papers, *ceteris paribus*, but they may not produce disproportionately more, as would be required to demonstrate the existence of economies of scale. The measurement of inputs is far from straightforward. The most common measure is that of numbers of staff employed, but most university departments and teams involve staff with part-time or split employment, visiting researchers, research students and so on. The counting of non-research-active staff may be particularly problematic as is the issue of what allowance (if any) one makes for time spent by researchers on teaching and other non-research activities. In addition, merely counting the number of staff does not allow for differences in quality. If there were a perfect labour market for researchers, one could perhaps use salary bills as a quality-adjusted measure of labour input; such an assumption evidently does not hold but this may nevertheless offer a better guide than simple head counts (assuming salary levels for a given 'quality' are reasonably uniform across the country).

7. Yet such problems with inputs pale alongside those involved in measuring outputs. Most of the studies surveyed here recognise that organisations such as universities are 'multi-product' in nature: they produce both teaching and research (and indeed are increasingly becoming involved in 'third stream' activities interacting with business and other 'users', although no study to date has apparently incorporated these). As with the input factors, the measurement of outputs comes down to three main issues:

a) What are the best measures of quantity?

b) How do quantity measures relate to measures of output quality?

c) And how can the various sub-measures be combined into an overall index?

8. There is only limited space here to consider the different methods of assessing quantity and quality. Some of the main bibliometric indicators and their limitations are as follows:

a) Simple publication counts: numbers of papers, with or without adjustment for numbers of pages. These make no allowance for quality, thus favouring ‘mass producers’ (Cole & Cole, 1973).

b) Quality-controlled publication counts: counting only publications in what are deemed to be top quality journals. However, the choice of such journals is often arbitrary, and generally tends to undervalue interdisciplinary work. In addition, other important forms of output such as books are not included.

c) Journal Impact Factors (IFs): weighting the number of publications by the ‘impact factor’ of the journal – i.e. the ratio of the citations that it earns from other journals to the number of references cited in its own articles. The IF number is subject to journal policies regarding citations and, because its distribution is very skewed, it can be unreliable for assessing small groups.

d) Citation counts: numbers of citations to the author concerned, usually based on data from the *Science* (or *Social Science*) *Citation Index*. The choice of journals is then dictated by the *Index* compilers (ISI), and many aberrant inclusions and exclusions have been pointed out. In the case of multiple authorship, the citations are credited to the first author, who may not always be the main instigator of the paper. There are major problems with mis-spellings of names, confusion of similar common names, self-citation and so on.

There has been little comparative analysis between these different measures, though a study by Colman et al. (1995) for UK politics departments found non-trivial differences between quality-controlled publication counts, simple publication counts and RAE ratings.

e) Data Envelopment Analysis (DEA): this technique allows one to identify what constitutes the ‘frontier’ in terms of the most efficient research units, and then to rank each specific research unit against that identified frontier. In this way, one can compare units that have similar characteristics to those at or near the frontier. The seminal study in the field (Johnes & Johnes, 1993) used DEA to assess both the ‘technical efficiency’ (e.g. publication performance) and the ‘price [cost] efficiency’ of UK economics departments, and pointed out that the two might not necessarily coincide. In our view, DEA, as an overarching approach, ought to be given more prominence in future studies.

9. Studies based on non-bibliometric methods include that for the UK by Glass et al. (1995), who took the Research Assessment Exercise (RAE) ratings as a measure of research quality. Yet this overlooks the point widely made in the aftermath of such assessments that panels may have been unduly influenced by the size of departments in judging ‘quality’ (e.g. Hoare, 1995, and work cited therein). The study might therefore be regarded by critics as showing little more than that RAE assessments were biased in favour of larger units.

B.3 Statistical Methods

10. To our knowledge, the statistical procedures deployed for assessing scale economies in research have never been critically reviewed. The study by Cohn et al. (1989), which set the standard for much subsequent work, involved a number of fundamental assumptions. The authors estimated a quadratic or translog cost function for US universities in 1981/2. Aside from data shortcomings, the cost function should ideally have been related to various outputs – quality of teaching, quality of research, etc. – whereas in fact all their data corresponded to inputs (e.g. enrolments of undergraduates and graduates, research grants won). As the literature on the performance on education establishments so often urges, what is really wanted is some measure of the 'value added' by such institutions. Yet this is not possible with input data alone. Most econometric studies apply only the simplest ways of adjusting for 'quality', typically by using publication counts (e.g. de Groot et al., 1991).

11. There are, however, some wider objections. The modelling assumes a one-way causation – more teaching and/or research leads to higher costs but, if scale economies arise, at diminishing rates. This assumes that enrolments (for teaching) and grants (for research) increase or decrease 'exogenously' (see the earlier discussion by Verry & Layard, 1975). Yet in practice it appears quite possible that the very existence of larger universities or departments may attract enrolments or grants to a disproportionate degree. Similar reverse-causation effects may take place with regard to cost functions such as those employed here. In the quest for 'value for money', research contracts might accrue 'disproportionately' to departments that are already seen as relatively 'cheap'. If so, we have the econometric problem of '*simultaneity*', and the coefficients thus estimated will be biased and inconsistent unless they can be 'identified' in some other independent way. In practical terms, the so-called 'Matthew effect' – 'to he that hath it shall be given' – may be self-perpetuating.

12. A second major problem with econometric approaches concerns so-called '*specification errors*'. The equations are estimated in quadratic form, implying that scale and scope economies take the form of smooth parabolas. However, the relationship may actually be highly non-linear, as it appears to be with large companies. In the case of UK academia, this may be linked to the Oxbridge or 'Golden Triangle' effect. As Hare and Wyatt pointed out in 1988, we know very little about the precise functional form of the relationship and whether it is quadratic in nature.

B.4 Economic Terminology

13. The notion of 'economies of scale' is outwardly self-evident but in practice is riddled with complexities and ambiguities. There is general agreement among theorists on two things: first, that 'size' can be measured in many ways related to inputs as well as outputs; and secondly, that 'scale' and 'size' are not the same thing. Scale is seen as relating to

'productive capacity' (e.g. Brinkman & Leslie, 1986), which may well differ from sheer size. Size may not increase capacity if it increases the complexity of operations to such an extent that any size-related gains are more than offset by the increased cost of that complexity (Gornitzka et al., 1998). Moreover, an existing 'static' efficiency of (say) a larger plant does not guarantee that its efficiency will grow faster in the future than that for a smaller one. Indeed, in a cross-country study of 17 OECD countries, Felderer & Obersteiner (1999) found that the highest-ranking country in terms of levels of scientific productivity, the USA, had the slowest growth rate. (This finding of an inverse relationship between levels and growth rates is also common in studies of industrial productivity.) Notwithstanding these complexities, the bulk of the literature concerned with research and education, no matter how grandly it is titled, turns out to be preoccupied with the relationship between performance and size (rather than scale) (Brinkman & Leslie, 1986).

14. So far as size is concerned, staff numbers are the usual measure, whereas 'scale economies' are almost always defined in theory with respect to **all** factor inputs, not just labour inputs. In science departments there may be substantial differences in equipment costs among institutions which should strictly be taken into account if one is going to interpret the results in terms of differences in efficiency (e.g. Hare & Wyatt, 1988).

15. Moreover, the underlying theory of a cost-minimising organisation, drawn from micro-economic analyses of for-profit firms, may not be totally relevant to public organisations with wider social responsibilities (see Brinkman, 1990; Getz et al., 1991; Dundar & Lewis, 1995). These authors point out, for instance, that an institution that was contracting would not be in the required state of cost equilibrium, as its costs are likely to be high in the short run; this might account for some of the apparent inefficiency of smaller institutions, which were disproportionately contracting in their sample. This comes back to the formal definition of economies of scale as relating to productive capacity rather than just size. Goudriaan and de Groot (1993) attempted to allow for departures from cost minimisation imposed by the regulatory activities of state governments on universities within their territory (they found some regulations actually decreased costs). However, the usual procedure can be justified by supposing that one is looking at non-profit institutions 'as if' they were out to maximise profits and minimise costs and 'as if' they were aiming at stability in size. Discussion of this subject would take us far afield; here we simply note that there is a complex issue to be taken into account.

C. Findings from Previous Studies

16. Let us now attempt to summarise the main findings of previously published work. Such findings are discussed sequentially from the micro units of individuals in teams up to the macro level. This is because, as will become apparent, the larger units can, to a certain

degree, be regarded as aggregates of smaller units, although some forms of economy of scale (such as those involved in administration) may arise only at the higher level.

17. As noted earlier, the unit of analysis is critical to the findings. Most of the earlier US-based econometric studies take the institution (e.g. the university) as the appropriate unit. However, in the UK attention has tended to focus less on universities and more on departments and whether there are size effects in relation to their research. We shall not dwell here on studies focusing on the national level since these are less relevant to current policy discussions in the UK. However, it may be worth noting that, in a cross-country study of 17 OECD countries, Felderer and Obersteiner (1999) claim to find some evidence of diminishing returns to labour and capital in terms of science output – i.e. dynamic dis-economies of scale at the national level. As implied in the discussion of dynamic scale economies above, this does not mean that extra science or R&D should not be undertaken, as there will still be *some* positive return – just not as much as before. They conclude that "it is the Anglo-American countries and small open European countries … e.g. Sweden, the Netherlands and Switzerland, that are leading" in terms of efficiency (for example, using impact factor measures – see ibid., p. 5).

C.1 Individuals, Groups, Teams and Networks

18. It has long been recognised that the distribution of scientific output is by no means normal. Lotka in the early part of the 20th century was perhaps the first to observe that the distribution follows a 'power law', with a large proportion of output in terms of numbers of publications being accounted for by a relatively small number of highly productive individuals. Rather surprisingly, this power law relationship has not been used to underpin econometric or similar studies, which instead retain the curvilinear functional forms already noted, presumably because these have a close association with broader investigations of industrial production. However, Katz (1999) has carried out an analysis based on a power law model and finds a remarkably good fit to the observed data at the macro level (see also Plerou et al., 1999). One of the implications, which Katz notes, is that it therefore makes little sense to talk about the 'mean' or 'average' when discussing such data, although this has not stopped many analysts from doing so.

19. Another implication that affects us even more directly here is that results from micro-level investigations are likely to be skewed according to whether or not very productive researchers ('stars') happen to be involved. The behaviour of such 'stars' has been studied in fields such as biotechnology (Zucker et al., 1998; also Nederhof & van Raan, 1993). The results clearly have a major bearing in relation to the present review of size effects. Are stars attracted to large departments or universities, for example by the resources they boast, or to smaller ones where the level of autonomy may be higher? We have not found any systematic

analysis of such a question that uses a broad-based sample, although there are some specific studies (e.g. Kyvik, 1995).

20. Since we are not concerned here with the output of individuals but rather with larger groupings, we immediately encounter measurement problems – in particular, how can one measure team size? For a particular group, there is often a fairly continuous turnover of researchers joining and leaving. In addition, an individual researcher may be a member of several slightly different groups for each of the research projects in which he or she is involved. Hence, many academics may be unable to give the size of the group in which they work. Moreover, data on group size are rarely available at the department or the university level. Consequently, those analysts who focus on the group as the unit of analysis often have to impute team size. A common measure of collaborative groups or networks is the extent of co-authorship of papers, sometimes within institutions, sometimes between institutions. Yet this measure is only an approximation (Katz and Martin, 1997). Furthermore, the degree of interaction in the teams identified on this basis may vary appreciably (Kretschmer, 1985).

21. The literature reveals that, whatever the field of research, the relationship between group size and research productivity is far from simple (see e.g. Hicks & Skea, 1989, for British sciences; Hemlin & Gustaffson, 1996, for Swedish arts and humanities). A typical finding is that productivity increases with size among small groups (Hicks & Skea, 1989; Qurashi, 1991) but there is then an inverse relationship for large groups (Diaz-Frances et al., 1995), with an optimal team size of around five to nine persons being observed in many sciences (Qurashi, 1993; Johnston, 1994). The review by Johnston (1994) is typical in finding a threshold size of about five persons, above which the relationship between group size and output becomes linear. Such a relationship between production and group size is also found by Seglen & Aksnes (2000) for Norwegian microbiology. However, not all studies observe this relationship. Cohen (1981, for biomedical research) and Kretschmer (1985, for molecular biology) find no optimal size – the relationship between size and output remains linear at all stages, implying that size has no effect on productivity.

22. Where training is the main focus rather than research, the optimal size of group in terms of technical efficiency may be even smaller – for example, groups of two or three have been found optimal in computer-based training (Stephenson, 1994). This rather traditional pattern of small-group training has, however, tended to disappear in recent years on financial (cost efficiency) grounds.

C.2 Departments

23. Qurashi (1993), in a study of British physics departments, observed a series of peaks of research productivity (i.e. local maxima), that, as he pointed out, represent close approximations to multiples of 8.5 staff. In other words, productive departments seem to be

composed of a series of teams, each of around the optimal size of eight or nine people on average. Hence, to the extent that there is an optimal size for the department, this may merely reflect the number of such teams making up the department. Qurashi notes that his numbers are strikingly close to earlier findings by National Cancer Institute for the USA in 1977, and are also supported to a certain extent by his own research on Greek mathematics departments. This finding, if true, would suggest that the optimal size of teams has a significant influence on the optimal size of departments.

24. However, other studies arrive at different conclusions. For the UK, Verry and Layard (1975) carried out an analysis using University Grants Committee (UGC) data on departmental costs for the late 1960s (although the accuracy and comparability of such data might be queried). They found no evidence of economies of scale at the department level (except in social sciences) once the time devoted to research and to teaching had been taken into account, though there were apparently economies due to high set-up costs for whole universities. However, they employed linear rather than quadratic or higher-order cost functions, which may disguise any economies of scale at low levels of output.

25. The seminal study by Johnes and Johnes (1993) of UK economics departments using DEA techniques found that the efficiency scores from this calculation were only weakly correlated with UFC selectivity ratings if individual research grants were included in the scores (but strangely the relationship became stronger if such grants were excluded). This suggests little if any causal relationship from selective research funding to efficiency. As for size effects, the authors again found no influence of departmental size measured by staff numbers on any form of efficiencies, whether technical or price.

26. In a study for HEFCE (Higher Education Funding Council for England) that focuses in part on the department level but also on the institutional (university) level, Adams et al. (2000) claim to find “a positive size effect on the quality of outputs in many of the natural and social sciences” (p.2). However, they do not look directly for evidence of economies of scale (i.e. by analysing the relationship between inputs and outputs), instead approaching the issue indirectly. They begin by noting that the size distribution of ‘units of assessment’ in the UK Research Assessment Exercise (RAE) – i.e. university departments in many cases – shows more small and more large units than they expected, at least in the case of sciences. The authors put forward the “hypothesis” that, as a result of the RAE, “management has been exercised on medium sized units and that this has led to the reduction of intermediate-sized low performers and investment and augmentation for high performers” (ibid., p.27).

27. Next, Adams et al. argue that comparisons with other countries (i.e. the *macro* level) show two things – that the degree of concentration of research effort is generally higher in the UK particularly in science, and that the UK also performs relatively well in science in terms of impact. They assume that there is some causal relationship between concentration and

impact (ibid., p.26) and thus arrive at the conclusion that “there is a positive size effect on the quality of outputs in most of the natural and the social sciences” (ibid., p.31). The set of assumptions in this claim are not discussed. However, the authors recognise that in mathematics, some social sciences, and arts and humanities there are many smaller units (or departments) operating at the highest levels of performance.

28. Moed et al. (1998) carried out an analysis comparing the effects of external research funding and basic research allowances in Flemish universities, using a wide range of citation and other indicators. They found that departments with the largest increases in external funding had published papers with higher journal impact factors (IFs) but produced similar outputs per head – i.e. such funds yielded better quality but a similar quantity of published output per capita. Bibliometric indicators suggested that getting bigger often *reduced* the average publication productivity, perhaps because of the increasing use of junior scientists.

29. A study by Gander (1995) of 31 departments of the University of Utah found that ‘ray average costs’ (i.e. the costs of increasing teaching and research side-by-side) were constant as departmental size increased, thus again suggesting a purely linear relationship between size and outputs rather than one exhibiting scale economies. (Nor did they find any clear relationship either way between teaching and research, as to whether expanding one helped or harmed the other.)

30. There have been several assessments of the benefits and disadvantages of working in large as compared with small departments (e.g. Zachos, 1991; Martin & Skea, 1992). Brown (1996) provides a summary of what US academics see as the advantages and disadvantages of working in a large or a small academic department. These include the following:

a) Large departments: pooling of budgetary and intellectual resources; higher cross-fertilisation of ideas and higher intellectual stimulus; greater possibilities for the sharing of teaching responsibilities among faculty members, thereby lessening the burden on individuals and hence leaving more time for research (similar to the earlier finding of Martin & Skea, 1992); higher probability of achieving the ‘critical mass’ required to compete for research grants; but less one-to-one interaction and less co-operation among researchers; and less involvement in the development of departmental policies.

b) Small departments: greater individuality, creativity and responsibility of researchers for their own areas; kudos for personal work environment that may offer more power; less internal conflict and more individual ‘niches’ for faculty staff; higher co-operation between researchers; but higher teaching loads that can have a deleterious impact on research performance.

C.3 Institutions

31. There have been a number of attempts to produce econometric estimations of the quadratic cost functions for ‘multi-product’ institutions (e.g. producing undergraduates, postgraduates and research), mostly in the US. The findings typically show scale economies operating only at fairly small institutional sizes, with a purely linear relationship in larger ones (e.g. Cohn et al., 1989). Furthermore, a very detailed sociological study by Hollingsworth et al. (forthcoming) reveals that the world’s most successful university in terms of winning major prizes in biomedical research has been a relatively small university in New York, where the social interactions between multidisciplinary groups were maximised. Similarly, although larger universities produce the bulk of the total output in Australian universities, when adjusted for size some smaller new universities appear to be more productive in terms of weighted impact factor measures (Davis & Royle, 1996).

32. In an analysis of the research institutes of the National Research Council (CNR) in Italy, Bonaccorsi and Daraio (2002) employ a range of input measures and output measures with a variety of methods including DEA. They find that the size of these institutes has no positive effect on scientific performance; rather it is *negatively* correlated in three of the six main areas they study (chemistry, environment and engineering). According to their results, *all* indicators of productivity decline with size – the most productive institutes again have five or six researchers in the fields studied, apart from medicine and biology where the optimum may be as large as ten. Lastly, they find that smaller institutes spend proportionately less, so they appear to be more cost-efficient as well.

C.4 Summary – Quantity and Quality

33. Overall, the studies at the various levels lend support to the notion of a ‘critical mass’ in relation to size, in which productivity increases rapidly as the size of the unit expands beyond having just one member. However, these economies apparently ‘expire’ rather quickly, as groups/teams, departments and whole universities or research institutes strive to find a balance between increasing interaction and cross-fertilisation, on the one hand, and a loss of efficiency from time spent on management and ‘bureaucracy’ (in the manner suggested by ‘Parkinson’s Law’), on the other. Furthermore, the point at which these economies peter out may be even lower when the quality of output, rather than just quantity, is taken into account. The optimal size of departments, to the extent that it exists at all, may be little more than some multiple of the optimal size of the teams within it (typically, around six or eight fairly permanent or longer-term researchers - i.e. including postdoctoral fellows but not generally PhD students), with the optimal number of teams in turn presumably depending on the breadth of coverage to which the department in question aspires.

34. Lastly, we should not ignore the likelihood that the formation of groups of near-optimal size may be almost 'self-organising', as individuals seek the conditions that are most attractive to them in units which perform comparatively well. In a study of university departments in a range of fields, Martin and Skea (1992) found that, although there was generally no deliberate policy on this, many had naturally evolved (on a self-organising basis) a sub-structure consisting of subfield-based groups, each typically with around six staff, a phenomenon observed in small departments and in very large ones.

D. Other Influences on Research Performance

35. In addition to size, a range of factors both internal and external to the research unit may also influence research performance. These may complicate or obscure any relationship between size and performance.

D.1 Fields and Disciplines

36. The optimal size for research groups is probably a little larger in applied research areas than in basic fields, as one might perhaps expect, but the evidence to hand comes from only a few studies (e.g. Bordons et al., 1996, for Spain). Thus, clinical-based biomedical research as in cardiology generates larger teams and more co-authorship than does pharmacology (Bordons & Zulueta, 1997).

37. An econometric investigation by Johnes (1997) for all UK universities in 1994/5 uses cost functions to compare them in terms of four 'products': undergraduate science teaching; undergraduate arts teaching; postgraduates; and research grants and contracts. He finds – rather surprisingly – that 'ray economies of scale' (i.e. those involved in producing these different forms of product side-by-side) are significant for relatively arts-based universities but do not exist even at the margin for the relatively science-based ones (see also Geuna, 2001).

D.2 Other Factors

38. The age of researchers and of institutions has sometimes been studied as a possible determinant of research performance, although the picture that emerges is not entirely consistent. One of the more careful studies is that by Bonaccorsi and Daraio (2002), who find a negative correlation between the average age of researchers in institutes and productivity. Yet even if productivity in terms of papers per year is found to decline with respect to age beyond a certain peak, older researchers may nevertheless act as 'gatekeepers', providing contacts and outlets for younger researchers. Thus, the overall team and departmental efficiency might well deteriorate if these seemingly less productive people are prematurely retired.

39. The size of institutes often tends to rise over time, but the age of institutes by itself may have a negative effect on productivity, as in the case of Italian research institutes (Bonaccorsi & Daraio, 2002). Hence the combined effect of these factors may be a *negative* link between size and productivity. For example, Davis and Royle (1996) find newer universities in Australia often overtaking older ones in terms of performance when adjusted for differences in size. In contrast, however, Cohen (1991) does not find any significant relationship between the age of institution and output per capita.

40. Sources of funding have been found to contribute to explaining some aspects of scientific performance, especially if one focuses on non-governmental research funding (e.g. Moed et al., 1998, for Flanders; Bonaccorsi & Daraio, 2002, for Italy). However, the issues here are complex and controversial.

41. The role of the organisational setting on research performance has been considered in several studies. The usual presumption is that a structured and well managed organisation will generate a better work response. For example, a major international study in the 1960s found that freedom and good management were important determinants of performance (Pelz & Andrews, 1966). However, in a study of Swedish arts and humanities by Hemlin and Gustaffson (1996), although organisation (in the form of leadership, strategy, etc.) turned out to be one of just two variables significant in a multiple regression, it had an unexpected negative sign.

42. An important study by Long and McGinnis (1981) found that the wider environment may determine productivity to a greater extent than the reverse – i.e. there is ‘simultaneity’ through mutual causality. They discovered that, after scholars arrive at a new institution, individual levels of productivity soon conform to the norms of the new rather than the previous institution. This is similar to findings in the management literature about the importance of corporate culture on performance.

43. Hemlin and Gustaffson (1996) found from questionnaire surveys that research productivity reflects a wide range of organisational, individual and external factors. The inability to distinguish between them may in turn reflect the fact that the factors are highly interdependent (Bland & Ruffin, 1992). The latter authors found participative governance correlated consistently and positively with research productivity, although other studies suggest differences between disciplinary areas in this respect (e.g. Chompalov et al., 2002).

D.3 Concentration Policies

44. We can find little evidence in other countries of explicit governmental policies aimed at the concentration of research resources in universities and their departments. The fact that national research systems can be very different, as in France, Spain and Italy where a significant proportion of research is concentrated in centralised research institutions, in any

case makes cross-country comparisons very difficult and potentially misleading. Felderer and Obersteiner (1999) find that such centralisation generally has a negative impact on research, but Breschi and Cusmano (forthcoming) argue that it may be important in winning EU Framework funding.

45. One example of an explicit policy of concentration is that being pursued in Japan (von Tunzelmann & Kraemer, 2003). In 2001, MEXT (the Ministry of Education, Culture, Sports, Science and Technology) launched the *Top 30 Project*, designed to raise the standards of Japan's top 30 research universities to the world's highest levels. Under this scheme, proposals prepared by the universities are subject to peer review by Japanese and foreign specialists who select the top 30 departments in each priority area. Although there have been considerable misgivings about this policy, many academics recognise the importance of other aspects of the policy such as having a separate funding framework for the programme and limiting the government's involvement to a supporting role, as well as accepting the need for effective internal decision-making mechanisms within universities in order to achieve this goal. In parallel with providing prioritised investment under the *Top 30* scheme, efforts are also being made in Japan to promote the establishment of networks of competence that overcome the current barriers to university-industry collaboration.

E. Conclusions and Policy Implications

46. It is often assumed by policy-makers and others that greater selectivity and concentration of resources in a smaller number of organisations will bring benefits in the form of economies of scale. Yet as we have seen, concentration may also bring certain disadvantages, whether (static) dis-economies of scale or a reduction in dynamic scale economies – for example, in the form of less diversity and experimentation in the approaches adopted by researchers to tackling the problems in their area.

47. International comparisons suggest that already research resources are quite heavily concentrated in the UK compared with many other countries. To some, it appears that the consequence of current UK Government policy is to encourage yet further concentration of research resources in large departments (in particular, large departments with a 5* rating in the last one or two Research Assessment Exercises) and in a small number of leading (and relatively large) universities. The justification for this seems to rest on the findings of the study by Adams et al. (2000) for the Higher Education Funding Council for England. That report claims to find "a positive size effect on the quality of outputs in many of the natural and social sciences". Yet, as was pointed out earlier, there are several untested and questionable assumptions involved in arriving at this conclusion.

48. One specific conclusion of Adams et al. that may well be influencing UK Government policy towards concentration at the institutional level (it appears as one of the first conclusions in the Executive Summary of the Adams report) is the following: "The greatest increase in performance, and the most significant growth, has been in larger universities with medical schools" (ibid., p.2). Many readers might infer from this some causal relationship between university size and performance, with larger institutions having benefited from economies of scale which enable them to be more 'efficient' in terms of producing outputs. Yet in order to reach such a conclusion, one must also take into account the respective *inputs* of larger and smaller universities. And as the Adams report reveals, over the period of this growth in output, there has been a very considerable increase in the proportion of funds going to the largest universities, with the proportion received by the top decile increasing from 47% in 1980/81 to 60% in 1997/98 (ibid., p. 16). If we set this against the finding of Adams et al. that "output has increased from larger HEIs at about the same rate as for smaller" (p.21 – a statement seemingly at odds with the earlier claim about larger universities in the report's Executive Summary), it is difficult to avoid the conclusion that, far from being more efficient, larger universities may actually have a *lower* productivity in terms of outputs per unit input. To reiterate, a finding that output has increased disproportionately from larger units is not sufficient to claim that, on efficiency grounds, moneys should therefore be diverted towards those larger units, and equally the fact that they have been so diverted still needs an economic justification to be made.

49. As we have seen in this review, although there is some empirical support for the notion of a 'critical mass' of researchers, the evidence is only convincing when the unit of analysis is the group or subfield-based team. If the unit of analysis is instead the department (generally spanning an entire discipline) or the entire university, then the evidence for any critical mass effect is ambiguous or contradictory. Moreover, this critical threshold for groups appears to be rather small (typically around six or eight researchers and in some cases maybe less), especially when quality is taken into account. Since departments may, from the point of view of research at least, be seen as essentially collections of teams, and universities in turn as collections of departments, the evidence base for a government policy that will result in increasing the already high degree of concentration of research resources on large departments and large universities appears to be lacking.

50. There may be more fruitful targets on which government could focus its efforts. As has been found repeatedly for private firms, it is generally not 'smallness' which is the main problem but 'loneliness'. Research and knowledge production, especially in the new era characterised by the studies described at the start of this report, thrive on cross-communication, inter-linkages, networks and collaboration. The integration of research teams into national and especially international networks appears to be a key determinant of

performance (although some might argue that there are plenty of inducements to integrate already).

51. One noteworthy point from econometric studies is that the most obvious gains from scale apply to teaching and research combined (‘ray economies’) – there is no consistent picture about specific economies from separating these functions or as between postgraduate and undergraduate teaching.

52. Finally, one should beware of drawing simple policy prescriptions from observed efficiency differentials. Most of the observed ‘scale dis-economies’ in higher education arise, if at all, in rather small universities (Brinkman & Leslie, 1986), so there may be a temptation to cut off the ‘tail’ of inefficient small units. However, one should not underestimate the vigour that small units can often impart, not least the competitive edge they can offer to potentially complacent larger units. In short, the performance of the system as a whole needs to be considered, not just that of individual units.

53. In studies such as this, it is a commonplace to conclude that “more research is needed”. Yet here, the considerable gaps in the evidence suggest more research is essential if government policy in relation to the allocation of research resources – and specifically whether these resources should be more heavily concentrated – is to be truly evidence-based. We have noted particular areas of ignorance. We have also suggested that methods such as Data Envelopment Analysis should be further explored in an attempt to clarify the situation. Wider consideration of whether size is a cause or a consequence of performance (or both) is also needed.

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