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Competition and pluralism in the public sciences: the impact of institutional frameworks on the organisation of academic science☆

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Abstract

The role of the public sciences in supporting the growth of new industries with radically innovative technologies has varied between countries that encourage different levels of reputational competition and intellectual pluralism and flexibility. These two characteristics of public science systems help to explain: (a) significant differences in the degree to which research is coordinated across universities and similar organisations to solve common problems and, (b) the ease with which new intellectual goals and approaches are developed and incorporated into research programmes to deal with new kinds of problems. They thus help to account for continuing differences in the rate at which public science systems produce highly novel intellectual innovations and deal with a variety of problems.

These characteristics of public science systems are in turn affected by four major features of the institutional frameworks governing the production of public formal knowledge in different countries. These are: the extent of state delegation of employment and resources control to scientific elites, concentration of intellectual and administrative control within research organisations, the stability and strength of the hierarchy of research organisations, and organisational segmentation of research goals and labour markets. Together these features help to explain major differences in competition and pluralism between public science systems.
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1. Introduction

Recent studies of technological specialisation in different market economies have emphasised the continuing diversity of national sectoral strengths and weaknesses in terms of their innovation patterns, and the strong connections between this diversity and variations in institutional frameworks (Guerrieri, 1999; Patel and Pavitt, 1994; Pavitt and Patel, 1999; Tylecote and Conesa, 1999; Vertova, 1998; West, 2002). Some of these comparisons have been stimulated by the marked contrast in the rate of development of new industries based on emerging technologies between market economies, especially where these technologies have been closely related to academic knowledge and skills, as in the computer hardware and software and biotechnology sectors (Bresnahan, 1999; Mansfield, 1995; McKelvey, 1996; Mowery, 1999; Narin et al., 1997; OECD, 2002). National differences in the speed with which radically novel technologies based on academic research have been developed appear especially marked in these industries, and clearly connected to

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variations in institutional arrangements. Accordingly, much research has focused on technology transfer mechanisms in different countries (Abramson et al., 1997; Branscomb et al., 1999), and the general role of universities and similar research organisations in stimulating new industries in different economies (Kenney, 1986; Rosenberg and Nelson, 1994; Shinn, 1998).

Rather less attention has been paid, however, to the consequences of national differences in the organisation and control of public science systems for innovation patterns, despite their considerable historical and contemporaneous variations (Ben David, 1971; Clark, 1995; Ergas, 1987; Kneller, 1999; Senker et al., 1999). Public science systems are understood here as the set of organisations whose employees undertake research primarily for publication together with the institutional arrangements governing their operation, including their funding, establishment of priorities, evaluation of performance and allocation of rewards. Research in the public sciences is largely oriented around the competitive pursuit of collegiate reputations for published contributions to collective intellectual goals (Dasgupta and David, 1994; Whitley, 2000), and researchers are rewarded mostly on the basis of those reputations. Technologically oriented research, such as that investigating the behaviour of artefacts and artificial materials, contributes to knowledge in the public sciences insofar as it is primarily directed at gaining such reputations. In contrast, research that is undertaken more for military or commercial purposes, and whose results are not publicly available, does not constitute part of the public science system.

The funding and governance of the organisations where published research is conducted, and of the ways in which research programmes are established and managed, continue to differ significantly between countries in Europe, North America and East Asia, as Clark (1995) has emphasised in his contrast of the "collegiate", "academy", "institute", "graduate department" and "applied" types of university systems established in Britain, France, Germany, the US and Japan. These variations remain mostly national ones because of the dominant role of the state in funding and controlling the institutions where publication focused research has been conducted over the past century or so, especially the nationally distinctive higher education systems. In a few "big science" fields, such as high-energy physics, research has become dominated by international laboratories and internationally coordinated programmes conducted at a few very large facilities. Even here, though, employment and careers remain predominantly national and structured by nationally distinct institutional arrangements.

As Krige (1992) points out in his discussion of teamwork at the European Nuclear Research Centre CERN, national groups and organisations constitute important bases for gaining resources and autonomy, as well as undertaking major tasks in constructing apparatus and generating results. Similarly, Abir-Am (1992; p. 176) has emphasised that, "International collaboration enhanced the position at home of those scientists who engaged in it by providing them with access to new scientific resources as well as with the clout of both real ... and apparent power" in the development of molecular biology. Nationally specific reputations and careers were here aided by membership of international networks in emerging sciences, not supplanted by them.

Where the connections between the development of emerging technologies and new public knowledge of generic phenomena and processes are becoming closer, these differences can be expected to impinge upon innovation patterns more directly than has traditionally been thought. Given, that is, continued variations in technological specialisation between market economies with different institutional frameworks, and in how public science systems are organised, together with growing interdependence between innovations and academically produced knowledge, we would expect countries with contrasting academic systems to display distinct forms of technological development. Exactly which aspects of public science systems influence national variations in technological specialisation, and how they do so, remain, however, somewhat unclear.

Differences in patterns of technical change are sometimes summarised in terms of the rate and type of technological change in different sectors, especially its discontinuity and disruptiveness (Casper, 2000; Ehrnberg and Jacobsson, 1997; Soskice, 1997). Where technical change is frequent and disruptive, research and development programmes cannot easily be planned in advance since the new knowledge that will be useful in dealing with technical problems is unpredictable and subject to change. This also applies to research skills and techniques so that

the ability to change direction, and to acquire new skills rapidly, are often crucial to success in developing new technologies in these kinds of sectors, especially where economies of scale and demand lead to winner-takes-all technology races (Shapiro and Varian, 1999). Firms in emerging industries that are dependent upon new public knowledge and the research skills that produce it often experience such high levels of technical uncertainty, partly because of the rapid production and unpredictability of new research results. They therefore develop close relationships with leading researchers and recruit newly trained scientists and engineers from their laboratories. In some cases, of course, these firms themselves are founded and staffed by established researchers, such as Genentech (McKelvey, 1996).

This flexibility, and ability to acquire, develop and use new knowledge about generic processes and phenomena, are facilitated more by some institutional arrangements than other ones (Casper and Kettler, 2001; Casper and Whitley, 2002). In the case of Silicon Valley and similar areas where high-technology industries have developed, of course, these have included flexible labour markets, knowledgeable venture capital groups and legal firms, as well as proximate research universities and technical training institutes (see, e.g., the papers in Kenney, 2000 and Lee et al., 2000; compare Aoki, 2000; Chapter 14). At the national level, though, they also include public science systems that are quite flexible in the sorts of intellectual goals they recognise as legitimate and ability to change them in response to external demands. Systems that are able to mobilise large numbers of specialists to deal with new intellectual goals and problems, and to train researchers in new techniques and ideas at relatively short notice, seem likely to produce a wide variety of knowledge and skills that could be useful to firms dealing with high levels of technical uncertainty.

At least one aspect of public science systems that could be expected to affect innovation patterns across countries with different institutional frameworks, then, concerns their flexibility and ability to mobilise intellectual commitments to dealing with new problems and issues. This in turn reflects variations in the degree and organisation of intellectual competition for reputations that are affected by, amongst other factors, national variations in employment structures, research funding arrangements and the organisation of higher education.

In this paper, I examine these connections through an analysis of the organisation and control of public science systems in terms of two key characteristics: the intensity of reputational competition between researchers and the extent of intellectual pluralism and flexibility. These affect the rate at which new ideas and approaches are developed and integrated into research programmes, as well as the ease of developing new research fields and careers that combine a variety of intellectual activities and purposes. They therefore, I suggest, influence the number of different goals and approaches that can legitimately be pursued by researchers seeking intellectual reputations as well as the integration of problem solving activities across organisational boundaries.

In the next section of the paper, the primary dimensions distinguishing public science systems that seem likely to contribute to differences in innovation patterns will be outlined. The subsequent section considers how these are influenced by the organisational arrangements governing the production of formal knowledge in universities and similar institutions. Finally, I shall suggest how particular connections between institutional frameworks and public science systems could be linked to distinctive patterns of technical change.

2. Competition and pluralism in public science systems

In comparing the public science systems of different market economies, it is important to recognise the distinctive nature of the modern sciences as particular kinds of coordination and control systems: reputationally controlled work organisations. These organisations structure the production of formal knowledge around the competitive pursuit of intellectual reputations for scientists' published contributions to collective goals as judged by their colleagues/competitors (Whitley, 2000). National and international coordination of research carried out at geographically dispersed locations in these kinds of organisations is ensured through the publication of codified knowledge in peer-controlled media, usually journals.

The extent of such codification, competition and coordination does, of course, vary between scientific fields, such as high-energy and solid-state physics, the chemical and biological sciences, and the social sciences, both within and across national scientific communities (Whitley, 2000). It also, though, is greatly influenced by the nature of the national institutional frameworks governing the public sciences. Differences between these frameworks affect a number of characteristics of public science systems that can be expected to impinge upon processes of technological development. Two particularly important dimensions of public science systems that affect the rate and type of intellectual change and vary between institutional frameworks are: (a) the overall level of competition between researchers for reputations from colleagues in the same field and, (b) the extent of intellectual pluralism and flexibility in developing new research goals and approaches.

Considering first the intensity of *reputational competition* in public science systems, this refers to the extent to which researchers seek recognition from their intellectual peers for the significance of their results in solving intellectual problems that are central to specialist fields. The greater is such competition, the more they have to convince colleagues/competitors of the importance of their research projects and influence others' work. This means that ideas and results have to contribute to collective intellectual goals and fit into current research programmes. In highly competitive academic systems, scientists attempt to influence the future direction of colleagues' research by establishing their research agenda as the dominant one, and their results as the key ones for future work.

Conversely, where public science systems exhibit relatively low levels of reputational competition, scientists have only a limited need to convince specialist colleagues in their "invisible college" of the worth of their research and to fight over the intellectual direction of research programmes in their field. In such societies, the importance of national and international collegiate reputations for career prospects and rewards is limited. This may be because there are a number of different kinds of audiences for research results that apply varied criteria of significance, and/or because goals and reputations are more local than national or international.

For instance, a low level of integration across employment units can arise in academic systems where researchers' dependence on local employers, and their controlling organisations in the case of state research institutes and similar employers, is greater than the need to obtain reputations from specialist colleagues. In these situations, rewards are tied closely to contributions to the dominant research programme in particular department or research institute, or else are largely dependent on organisational seniority, as in many postwar Japanese universities (Coleman, 1999; Kawashima and Maruyama, 1993; Sienko, 1997). Here, researchers do not actively have to gain national or international reputations for their research programmes and approaches in order to gain promotion. Intellectual careers are thus more local than cosmopolitan and often built around the development of long-term programmes.

This characteristic of public science systems affects the extent of intellectual integration of research goals and results across organisational boundaries, and of collaboration between scientists working on common problems in different locations. Where reputational competition is strong, new ideas, findings and approaches become more quickly communicated and incorporated into research projects, and intellectual problems should be resolved more speedily. This means that, *ceteris paribus*, the rate of new knowledge production about common intellectual problems should be greater in societies that encourage reputational competition than in those that do not do so. They mobilise more resources to deal with central problems through intense competition for personal reputations than do science systems with limited reputational competition.

As a result, knowledge production about high-priority topics will be more integrated and focused on collective goals in highly competitive science systems. From the point of view of generating new knowledge that might be technologically useful, then, once research goals closely related to technological objectives become central to a field, they will receive more highly coordinated attention in competitive science systems than where competition is lower.

Second, public science systems vary in the level of *intellectual pluralism and flexibility* in changing research goals that they encourage. This refers to the ease of gaining public reputations for different kinds of

contributions to a variety of intellectual purposes and being able to change these in the relatively short term. Where such pluralism and flexibility are high, scientists can pursue a wide variety of intellectual projects with distinctive goals and approaches. They are able to develop competing research programmes that focus on different phenomena with contrasting theoretical models and technical procedures. Scientists in such societies will probably be relatively eclectic in their intellectual objectives.

This suggests that they will be more tolerant of work that contributes to a variety of goals, and to be willing to change direction, than researchers in relatively constrained science systems. Countries with more pluralistic and flexible systems are more likely to encourage research that seeks both to understand fundamental physical and biological processes and to deal with technologically oriented issues, such as that summarised by Stokes (1997) as "Pasteur's quadrant". One recent example of this kind of work is concerned with understanding how cells organise, develop and function at the level of living systems as a contribution to tissue engineering (Murray, 2002).

Other things being equal, linkages between technological problem solving and reputationally oriented research in universities should be easier to establish and maintain in these circumstances. Additionally, new fields focused on technological concerns can become institutionalised relatively easily as legitimate areas for researchers to gain reputations in such countries, and so enable academics to pursue new kinds of research questions within the reputationally controlled system. For example, the development of computer science in some leading US research universities is often cited as an example of their flexibility that helped to develop the computer industry in the US (Bresnahan, 1999; Mowery, 1999).

In contrast, in less pluralist and flexible public science systems researchers deal with a more limited number of major intellectual problems that do not change greatly over the short to medium term. They are quite highly constrained in the topics they choose to study and the approaches they adopt by current intellectual trajectories. The types of research that are regarded as legitimate tend to be restricted in such systems, and establishing new fields or intellectual approaches is often difficult. Such systems often encourage long-term research programmes organised around major disciplinary goals, as well as investment in a limited range of research technologies. However, they can discourage the integration of diverse types of knowledge and intellectual approaches as well as the generation of radical intellectual innovations.

For instance, in countries where intellectual pluralism and flexibility are limited by relatively centralised control over research programmes and resources, both within employment organisations and in state bureaucracies, it is unlikely that researchers will find it easy to pursue distinctly individual intellectual objectives with idiosyncratic approaches. Equally, where researchers' employment and careers are highly segmented between different kinds of knowledge production, such as that focused on theoretical purposes and that concerned more with technological applications, it will be difficult to combine different types of intellectual objectives, or to change them.

Combining and dichotomising these two dimensions enable us to distinguish four ideal types of public science systems, as summarised in Table 1. Considering first what might be termed *competitive pluralist* systems, these encourage pluralism and flexibility but also institutionalise intense competition for intellectual reputations, and so generate a variety of different kinds of highly coordinated intellectual

Table 1
Types of public science systems

Level of intellectual pluralism and flexibility	Intensity of reputational competition	
	Low	High
Low	*Differentiated hierarchies*: encouraging incremental intellectual innovations in centrally planned programmes	*Competitive hierarchies*: encouraging highly coordinated contributions to disciplinary goals within established frameworks
High	*Differentiated pluralist*: systems encouraging diverse programmes in different organisations dealing with varied problems	*Competitive pluralist*: systems encouraging intellectual risk taking and varied, changeable approaches to common problems

innovations. Here, researchers struggle to dominate scientific and technological fields by developing their own approaches to major problems and so a considerable variety of research programmes and alternative theoretical approaches are likely to be produced, with many of these drawing on ideas and findings from a variety of different areas. They are encouraged to differentiate themselves by pursuing distinctive kinds of objectives with novel techniques, and to be flexible in adapting to new knowledge and opportunities.

However, because intellectual careers are closely dependent on collegiate recognition in these fields, researchers are unable to simply pursue their own projects in isolation from each other, but have to convince their peer group of the importance of what they are doing. This means that considerable novelty and variety of goals and models are combined with high levels of intellectual coordination and integration achieved through common research procedures and routines. While techniques may vary in their formalisation and standardisation, they have to be sufficiently shared and unambiguous for results to be understood and used in similar ways by intellectual colleagues in different locations in these kinds of public science systems.

As a result, competitive pluralist systems encourage intellectual risk taking within current technical norms as researchers develop distinctive approaches to deal with intellectual problems, and are relatively open to the establishment of new fields that are reputationally controlled. They are therefore capable of generating a considerable amount of new knowledge about a variety of problems, including those relevant to technological issues, thereby contributing to the development of radically new technologies that involve using many different kinds of knowledge to deal with unforeseen and frequently changing problems. As Mowery and Rosenberg (1998; p. 175) point out, the flexibility of the US public research system led to the mobilisation of large numbers of researchers and resources to deal with problems in solid-state physics once the transistor had demonstrated the potentially high technological payoff of such research. Such systems seem less likely, though, to encourage long-term investments in highly uncertain research programmes that may revolutionise scientific fields, because the intensity of competition for reputations and resources focuses attention on relatively short-term goals and outputs.

Second, what might be termed *differentiated pluralist* science systems combine weak competition for national and international collegiate reputations with low levels of intellectual constraint on research priorities and approaches. These enable scientists to pursue diverse goals and approaches with different research methods, such that intellectual contributions can easily become fragmented and incomprehensible to others, depending on the organisation of employment units. Where authority within universities and other research organisations is strongly hierarchical, integration will be greater within organisations, but weak across such boundaries. Local schools of thought based on divergent philosophical and theoretical positions can develop in such situations that, depending on the organisation of academic labour markets, may rarely communicate with each other.

Competition in these kinds of science systems is less focused on common problems and issues within fields, and more on alternative conceptions of what the central problems and frameworks should be. Intellectual innovations tend to be fragmented across research sites, and incremental within them. While individual groups in technologically focused organisations may become linked to the development of particular technologies and sectors in such systems, the level of coordinated research across employment units that could contribute to such development will be limited. Technological goals may, then, become the focus of some researchers in these kinds of public science systems, but contributions to such goals will not be strongly integrated across research sites.

Third, *competitive hierarchical* public science systems combine high levels of reputational competition with strong disciplinary control of research agenda and pressures to conform to current intellectual norms. Researchers here compete intensively for reputations on the basis of their contributions to widely agreed intellectual objectives with standardised concepts expressed in a common language and shared techniques. Conflict over the criteria for assessing competence and success in achieving intellectual goals is low in such science systems and challenges to the prevailing orthodoxy are unlikely to be successful in the short to medium term.

The range of intellectual problems considered, and the ability to shift research goals, are limited here so that both the variety of goals and conceptual

approaches and the rate of major intellectual changes are relatively low. Innovations are highly coordinated around common objectives such that new knowledge is rapidly incorporated into collective research programmes and progress in dealing with key issues is relatively fast. These kinds of science systems encourage long-term disciplinary development within established intellectual frameworks, but are unlikely to tolerate radical innovations that threaten those frameworks. Applied research goals will be less prestigious and rewarding than core disciplinary ones, and so the development of new fields oriented to both explanatory and practical purposes difficult to accomplish in these kinds of public science systems.

Fourth, *differentiated hierarchical* science systems combine considerable intellectual constraint with lower levels of reputational competition. These also limit variety and novelty but with reduced collective evaluation and integration of projects and results across research locations. Here, scientists may be quite constrained by centrally determined programmes and objectives, but do not need to convince colleagues elsewhere of the value of their contributions as intensely as in the previous case. This lower intellectual coordination of results across research sites seems likely to reduce the flow of new information and the rate at which researchers adapt to new knowledge, as well as increasing the difficulties of mobilising intellectual resources in different organisations around new problems. Innovations in such systems are, then, probably going to be quite effective at dealing with relatively predictable problems that can be specified in advance, but less useful in fields with greater intellectual uncertainty. They are therefore less likely to generate radically new theories or understandings of phenomena.

When directed towards systemic goals for which research can be reliably planned with current techniques and approaches, these kinds of public science systems can be highly effective, as in the development of large-scale technological systems (Kitschelt, 1991). While supportive of technological goals that depend on current frameworks and trajectories, though, they will be less useful or generating novel technologies that involve the understanding of new kinds of phenomena and processes.

These two characteristics of public science systems are developed to contrasting extents in different societies as a result of variations in their institutional frameworks governing formal knowledge production. These include the considerable differences in university structures and funding arrangements, in state science and technology policies and practices, such as those contrasted by Ergas (1987) and others (Doremus et al., 1998), and general patterns of labour market organisation and scientists' career paths. I now turn to consider how the most significant features of these frameworks influence the degree of reputational competition and intellectual pluralism and flexibility of public science systems.

3. Institutional frameworks governing the public sciences

The degree of reputational competition and intellectual pluralism and flexibility in public science systems are affected by at least four distinct features of national institutional frameworks. First, the general degree to which the funders and employers of researchers, principally the state but also other groups, are willing to delegate control over research goals, performance and assessment to practitioners through competitive peer review procedures. The extent of such delegation has changed considerably over time (Elzinga and Jamison, 1995; Guston, 2000; Slaughter and Leslie, 1997), but it also differs between states, as does the way it is organised. Second, there are important differences in how work is organised and controlled within universities and other research organisations between societies, as well as in the procedures governing promotion and other rewards. Third, the extent to which such organisations are ordered into a stable hierarchy of prestige and resource control differs considerably between national research systems. Fourth, scientists' and technologists' labour markets, research goals and performance standards are segmented between organisations to different degrees in different countries.

Considering first the willingness of the state, and other providers of research funds, salaries and infrastructure, to delegate control over employment decisions and resource allocation to research practitioners, this affects the extent to which researchers are collectively able to control the standards governing research priorities and performance evaluation. By relying on peer review to assess the merits of research

projects, on scientific journals to decide the worth of research results, and on practising researchers to evaluate the qualities of job applicants and promotion candidates, states effectively institutionalise intellectual reputation as the key to rewards. They thus substitute reputational control for bureaucratic direction and evaluation. By definition, all public science systems are institutionalised in countries with some such state delegation, but the extent of decentralised control over jobs and resources to practitioner elites clearly varies between, say, France, Germany, Japan and the US in the postwar period.

Where states and other funding agencies limit such delegation and retain considerable central control of funding, intellectual competition and coordination across organisational units remains restricted. This need not, of course, imply that scientists do not compete with each other in such circumstances, merely that they compete for different kinds of recognition, awarded for contributions to different objectives and assessed by different groups of people. Bureaucratic and/or political objectives are more important in such circumstances than theoretically driven intellectual ones. As Clark (1995; p. 107) suggests of the French CNRS, "The competitive struggle of subunits (for improving their officially defined status) within this mammoth research bureaucracy is often fierce".

A critical dimension of such delegation here concerns the extent to which it involves the allocation of research resources for public policy goals to investigators in universities and similar autonomous organisations through competitive peer review as opposed to concentrating research programmes in state laboratories and/or centrally administering them. Highly decentralised science systems in this sense, then, not only delegate employment and promotion decisions to autonomous universities and similar research organisations, but also rely extensively on competitive peer review processes to allocate substantial research resources for both theoretical and policy purposes. This feature of institutional frameworks can be termed the extent of *state delegation of control to researchers*.

The second important institutional feature that affects the nature of public science systems concerns the organisation and control of employment opportunities and promotions in academia and other organisations producing published research. The concentration of control over intellectual goals and key resources within universities and research institutes varies considerably between the academic systems of Europe, North America and East Asia (Clark, 1995; Hollingsworth, 2000). Very broadly, most Anglo-Saxon systems since the war are more pluralistic and varied in their authority structures than are those influenced by the Germanic model of research institutes headed by a single professor.

In the former, relatively decentralised authority systems, the post of department head typically rotates between the full professors, of whom there are a number, and each established faculty member pursues his or her own research with a team of doctoral students and post doctoral researchers. They often compete nationally for research funds, and work on different problems with limited departmental coordination. Here, the primary unit of knowledge production, the research team, is distinct from the main unit of administrative control, the department. Such employment systems facilitate considerable variation in topics, models and techniques between researchers, and enable intellectual change to develop within employment units as interests and priorities alter (Feller, 1999; Stokes, 1997).

In contrast, the more centralised, "Germanic", system of research institutes is built around the single-Chair incumbent who develops a distinctive research programme that characterises each institute as long as they remain there. Both intellectual and resource control authorities are here clearly located in the hands of the full Professor who determines the division of labour within the group and integrates results around a single set of intellectual objectives. Research here is highly coordinated and relatively narrowly focused, with major intellectual change occurring only when the institute head retires or moves. Such systems encourage long-term research programmes, but can inhibit intellectual variety and change (Clark, 1995). This feature of employment systems can be characterised as the degree of *employment centralisation of control*.

As well as authority relations within research organisations varying greatly between national science systems, they also differ considerably between them. The third dimension of the institutional frameworks governing these systems to be considered here concerns the extent to which intellectual prestige and control over the allocation of research resources are concentrated in a few central academic institutions.

The stability and strength of such hierarchies affects the intensity of competition between research organisations for scientific leadership by limiting access to human and material resources for the less favoured ones.

For example, in the more centralised states with stable hierarchies of academic prestige, such as postwar France, Japan, and perhaps Britain (Blume, 1974; Farin and Gibbons, 1981; Gaston, 1978), control over intellectual goals and research funding is often quite centralised in the hands of a small elite of senior staff at the leading institutions, even when the state does delegate discretion to scientists. In contrast, federal states and countries where there are a number of non-state funding sources, such as charities and foundations, may well exhibit greater pluralism in the criteria they apply when allocating funds (Feller, 1999; Stokes, 1997). In such cases, concentration of control is often low enough to permit considerable variety of research goals and approaches to develop, and the novelty of intellectual contributions will be correspondingly greater.

The critical feature here is the extent to which strong and stable hierarchies of intellectual and social prestige among universities and similar organisations enable relatively small and cohesive elites to determine the standards governing access to key resources in most scientific fields, and so can insist on their research agendas being followed. Generally, we would expect countries with centralised state systems and where states administer mission-oriented research programmes centrally through a single ministry or academy of science to be likely to concentrate intellectual control in the hands of an elite.

An important aspect of such hierarchies of research organisations concerns the level of competition between them for resources and intellectual prestige. In highly concentrated and hierarchical academic systems, the best researchers are not only recruited and trained in the leading organisations but are also likely to remain in them for most of their careers because of their superior status and resources. More peripheral universities are rarely able to improve their standing through attracting leading scientists, or by acquiring better facilities through competitive processes. Open competition between research organisations in such societies, therefore, is quite limited, as is mobility between employers in the course of scientific careers.

On the other hand, in countries with a number of competing research universities that are funded in different ways by a variety of agencies pursuing different objectives, together with different kinds of research organisations also competing for scientific prestige, it will be more difficult for such groups to monopolise intellectual goals and standards. In the case of the postwar US research system for instance, the variety of state funding agencies, and of Congressional committees overseeing them, has probably encouraged intellectual competition and pluralism (Stokes, 1997). More generally, the variety of institutional forms, high level of decentralisation and institutionalisation of competition for prestige and resources in the US academic system has encouraged universities and colleges there to compete with leading institutions in a way that is unusual in much of Europe and Japan (Feller, 1999; Graham and Diamond, 1997).

Generally speaking, the greater the rate of competition between research organisations for prestige and resources, and the more mobile are scientists in seeking promotions, the more ideas and skills circulate between departments, and the more likely intellectual change and novelty will increase. Such mobility is affected by broader patterns of labour market organisation that vary across market economies, as well as by the nature of competition between universities for leading researchers. As Ben David (1971) suggested many years ago, the intellectual achievements of the German university system in the 19th and early 20th centuries were encouraged by the relatively decentralised and competitive nature of that system, in which scientists expected to move between employers to gain advancement on the basis of their intellectual reputations. These features of academic systems can be summarised in terms of the *stability and strength of the hierarchy of research organisations* producing public knowledge.

Fourth, another important feature of national institutional frameworks that can affect the organisation of the sciences is the organisational rigidity and segmentation of goals and resources between different employment units. This refers to the strength of the separation and division of labour between research universities focused on the production of theory driven knowledge for intellectual reputations, applied research institutes, technology transfer agencies, research association laboratories and private

companies. Where these have quite distinct goals, funding arrangements and control procedures, so that researchers in them are trained in different ways, do different kinds of work and have separate career paths, the degree of *organisational segmentation* is high. In such systems, researchers are discouraged from undertaking a wide variety of types of research, including that focused on technological and commercial objectives, within universities, and from moving between different kinds of employers without suffering a great loss of intellectual credibility.

Knowledge and skill transfer between types of research organisations will be relatively slow and difficult in highly segmented public science systems. Rapid technological responses to new research results are unlikely to occur here, and technological trajectories will continue to develop largely in isolation from radical intellectual innovations. For example, the separation of much biological research from medical schools and hospitals in France, Japan, and perhaps Germany, has been seen as inhibiting the development of biotechnology firms in these countries (Henderson et al., 1999; Kneller, 1999; Thomas, 1994).

In contrast, where organisational segmentation is lower, research organisations have overlapping goals, contain a variety of kinds of research activity and have overlapping labour markets, funding arrangements and control procedures. As a result, knowledge and skills flow more easily between them and the development of joint projects between researchers from different employment units and fast adaptation to new knowledge is facilitated. Low segmentation can also allow academic scientists to pursue a variety of objectives more easily, and thus transfer their results directly to the development of new products and processes, than in more segmented environments. As Stokes (1997: p. 45) points out, it has long been a feature of the US research system that many organisations, such as research universities and Bell Labs, have provided a home for researchers pursuing both theoretical and applied goals. The founding and development of Genentech exemplify these low levels of organisational and goal segmentation in the emergence of the US biotechnology industry (McKelvey, 1996).

To some extent, this contrast can be observed in recent accounts of the German and US innovation systems, although the degree of segmentation and rigidity in the former country remains debatable (Soskice, 1997). Again, postwar Japan might represent a strong form of organisational segmentation of researchers' careers, at least as far as the national universities are concerned (Barker, 1998; Clark, 1995; Coleman, 1999; Kneller, 1999; Yamamoto, 1997), although some recent changes to the status of universities and academics may alter this (OECD, 2002). These four features of the institutional frameworks governing public science systems affect the degree of reputational competition and intellectual pluralism in different ways that are summarised in Table 2 and will now be considered in more detail.

I first discuss the factors affecting the intensity of competition for intellectual reputations. Broadly speaking, this reflects the dependence of researchers' careers and access to resources on their reputation amongst their national and international peers. Therefore, any institutional arrangement that increases the importance of such intellectual reputations will, *ceteris paribus*, lead to higher levels of reputational competition.

Clearly, this means that public science systems where the state and other employers and funding organisations delegate control over careers and resources to transorganisational peer groups are more likely to exhibit high levels of reputational

Table 2
Connections between institutional features and characteristics of public science systems

Institutional features of academic systems	Characteristics of public science systems	
	Intensity of reputational competition and flexibility	Intellectual pluralism
High state delegation of resource control to researchers	High	High
Strong centralisation of decision making within employment organisations	Varied	Limited
Stable and strong hierarchy of research organisations	Limited	Low
Strong organisational segmentation of goals and careers	Some	Low

competition than those that do not do so. As well as decentralising employment and promotion decisions to autonomous universities, this also refers to the decentralisation of control over research funds granted for public policy goals to peer groups. Competition in such situations will, of course, be further intensified when the number of competent researchers produced by the academic system grows at a faster rate than the number of jobs available in research organisations, as happened in the US towards the end of the 20th century (Feller, 1999; Noll, 1998).

The second most important factor is the stability and strength of prestige and resource hierarchies of research organisations. Fluid and weak hierarchies encourage employers to compete in the market for national and international intellectual prestige by attracting leading researchers. Accordingly, such public science systems are likely to generate greater levels of reputational competition than are those in which an elite group of institutions dominate the academic system. This is especially so in countries where there is an active labour market in researchers as well as a decentralised grants system that enables scientists from a wide variety of institutions to compete for resources on a continuing basis.

Third, organisational segmentation may also encourage greater dependence on peer group reputations, and so increased intellectual competition, because researchers' key audience for ideas and results is more focused on particular kinds of goals than on a plurality of them. They therefore have to convince disciplinary peers that their contributions are significant for dealing with a narrower range of intellectual problems than in societies where segmentation is lower and they can communicate results to a wider variety of legitimate audiences. This relationship, however, seems likely to be less important than the level of state delegation and inter-organisational competition since these institutionalise the competitive pursuit of reputations from colleagues though labour markets and resource allocation criteria.

The impact of employment decentralisation on reputational competition varies according to the level of organisational competition for intellectual prestige. If this is considerable, then the individual researcher's reputation becomes more important than the department's in decentralised organisations. In such systems, research entrepreneurs attempt to dominate fields as much on their own as part of a departmental or sectional enterprise. More hierarchical control of research goals and approaches within universities, on the other hand, leads to reputational competition between research institutes as much as between individual research groups in competitive academic systems. While this may be quite intense, it limits the pressure on junior scientists to seek individual reputations in order to obtain resources. It may also substitute internal competition for contributions to the local research programme for national and international competition.

Considering next the connections between these institutional features and the degree of pluralism and flexibility encouraged by public science systems, the centralisation of control over research goals, resources and careers within and between universities and similar organisations is especially significant. Generally speaking, the more concentrated is control over jobs, promotions and other rewards, as well as over the allocation of resources, the more constrained researchers become to follow dominant views of important objectives and how they should be attained. Thus, societies with centralised state control over resources, and/or where the academic system is strongly hierarchical—both within and between universities—are likely to develop public science systems that limit the degree of intellectual pluralism and flexibility. Equally, low rates of competition between employers for leading researchers reduce mobility and the likelihood of changing direction or adapting to new approaches in the short to medium term.

Additionally, highly segmented research organisations restrict intellectual flexibility and novelty because they reduce the speed and frequency of circulation of new ideas, and make it more difficult to access ideas from outside the institute or field. The development of new areas of study and novel research programmes is therefore less easy in societies with centralised control in employment organisations and stable academic hierarchies of prestige and resource control, as well as firmly segmented organisations, than where boundaries and hierarchies are more fluid.

These relationships suggest that competitive pluralist public science systems are most likely to develop when control over resource allocation and employment is highly decentralised to competing universities that undertake a variety of types of research.

Exemplified perhaps by the institutional framework governing the postwar US academic system, this combination of considerable state delegation, employment and academic decentralisation and low organisational segmentation has established a highly competitive research system that is quite flexible in developing new goals and fields (Cohen et al., 1998; Feller, 1999; Noll, 1998). It also encourages varied careers and roles for scientists, especially in the biomedical sciences where strong state support for policy-oriented purposes has been managed in a decentralised, but coordinated manner (Stokes, 1997).

In contrast, differentiated hierarchical science systems are more likely to develop in countries where state delegation of resource control is limited, centralisation of authority in employment organisations is considerable and there is a strong and stable prestige hierarchy of universities. Postwar Japan perhaps comes closest to representing this kind of society (Clark, 1995; Coleman, 1999). Competitive hierarchical systems, on the other hand, probably occur where there is some state delegation to practitioner elites and competition between universities, but the academic system is quite centralised and hierarchical within them so that disciplinary elites and institute heads can exert considerable control over research agenda and careers. The German institute model of universities seems to reflect many of these aspects (Clark, 1995). Finally, differentiated pluralist forms of public science organisation are most likely to arise in situations where careers and resources are more locally controlled, authority is relatively decentralised and mobility is limited.

4. Discussion

In summary, because national educational systems, state science and technology policies, the organisation and control of research funding and evaluation, and the segmentation of research organisations continue to differ, so too do the ways that the public sciences are organised and develop in each country. Such variations in the organisation of labour markets, university hierarchies, state science and technology policies, and other features of national research systems, can be expected to affect the development of novel technologies and products through differences in the intensity of reputational competition and degree of intellectual pluralism and flexibility. As a result, societies with public science systems that diverge significantly in these respects will probably manifest contrasting patterns of technical change.

For example, discontinuous, radical innovations often use new knowledge from a wide variety of sources to deal with novel problems as and when they crop up, and are difficult to plan for through systematic investment in structured programmes of formal knowledge production. Since new technologies involving novel architectures usually generate large numbers of unexpected problems, their development is often a matter of trial and error learning in which it is unclear what sorts of knowledge will prove useful. Planned research projects generating incremental intellectual innovation are here less likely to prove effective than being able to gain rapid access to a wide variety of new information and to develop new research projects quickly around novel problems and issues. Public science systems that combine the coordinated production of differentiated and varied specialised knowledge oriented to diverse goals with considerable intellectual and organisational flexibility may be particularly suited to the development of such technologies.

In contrast, technological trajectories that are more stable and predictable enable systematic research programmes for technical changes to be developed and investments made in a relatively limited number of scientific and technological fields. Developing these kinds of sustaining technological innovations is facilitated by an education and research system that produces a considerable number of knowledge producers that can work effectively within current technological trajectories and can keep up with new knowledge generated by others. It is also assisted by the establishment of intermediary organisations and agencies for developing applied scientific and technological knowledge and diffusing more theoretically-oriented knowledge when it enhances existing competences. The sorts of state supported institutions for coordinating knowledge development and diffusion across a range of industries that have been elaborated in Japan, Germany, Sweden and other continental European countries within the broad heading of diffusion-oriented science and technology policies seem to fulfil these functions quite effectively (Ergas, 1987; Soskice, 1997).

Long-term research programmes that deepen our knowledge of particular phenomena, techniques and materials may be helpful for such innovations since they provide a steady stream of new information and ideas for improving technologies and upgrading products within the broad confines of currently dominant designs and technological trajectories. The sort of "reverse salient" pattern of technological research identified by Hughes (1987) represents such an approach, although it may of course lead to more radical changes in time.

Research systems that focus more on rapid responses to new ideas and information, and radical shifts in research priorities, techniques and theoretical approaches may not, then, be particularly useful for such developments, at least not directly. This is particularly likely when research is integrated with the training of new researchers through using doctoral students on research projects so that Ph.D. graduates become accustomed to competitive and innovative styles of research, rather than more routine puzzle solving. Such scientists and engineers might then not be very attractive to many employers, who may prefer to recruit graduates with Masters degrees instead. This has been the case in Japan for much of the postwar period, where around six times as many masters graduates as doctoral ones were employed in the late 1990s (OECD, 2002; p. 165; see also, Ogura and Kotake, 1999; Sienko, 1997; West, 2002; Yamamoto, 1997).

This analysis suggests that we can distinguish between at least three ideal types of institutional frameworks and public science systems that are likely to be associated with distinct patterns of technological development. First, countries with relatively centralised and hierarchical university systems, where scientists' and technologists' careers are additionally highly segmented, are unlikely to develop highly novel and disruptive technologies closely based on new formal knowledge produced by the public sciences. In general, such societies limit the development of research programmes that combine technological goals with the fundamental understanding of generic processes and incorporate varied kinds of knowledge and skills. Intellectual entrepreneurship and pluralism tend to be restricted here, as does the pursuit of careers that combine academic and entrepreneurial activities.

Industries that depend on the rapid solution of complex technical problems with generic knowledge of physical and biological phenomena are accordingly unlikely to be easily developed in such societies. However, these kinds of institutional arrangements can provide strong support to cumulative technological developments, especially where these are largely undertaken within firms that rely on the academic system to produce highly trained technologists rather than autonomous knowledge producers.

Second, the combination of considerable state delegation to relatively autonomous universities and research organisations with significant levels of authority centralisation within employment units and organisational segmentation of goals and careers, as occurs in some continental European countries, is likely to generate highly coordinated research programmes focused on common goals, but perhaps with limited intellectual risk taking in the short to medium term. Because recognition and careers are segmented between types of objectives and employers in such societies, technologically focused research is unlikely to be pursued by scientists seeking collegiate reputations for their contributions to theoretical goals. They are equally unlikely to pursue any potential technological implications of their work, let alone to commercialise them. Spillovers between theory-driven research and technological development will therefore be limited in such economies.

However, the extensive set of public and quasi-public research organisations devoted to technological objectives in many of these kinds of societies facilitate the integration of codified generic knowledge with design goals, albeit indirectly and usually within current technological trajectories. This combination of characteristics, then, is well suited to the development of continuous, cumulative innovations within current established technological trajectories, as Casper et al. (1999) and others have suggested is the case for many industries in postwar Germany.

Third, countries that have highly decentralised research systems with strong competition between universities for intellectual prestige and leading researchers, coupled with decentralised authority structures within research organisations and low segmentation of objectives and careers are more likely to generate different kinds of formal knowledge about highly varied phenomena from a number of approaches. They are also likely to encourage relatively frequent restructuring of intellectual programmes and

models as priorities change. Such frameworks stimulate the development of intellectual entrepreneurs who are willing to take considerable risks and to pursue a variety of different kinds of research goals and careers. As a result, they will be more supportive of the development of radically new technologies with numerous unforeseen problems that require formal research to deal with than less competitive and risk taking ones. This suggests that new industries reliant on use-inspired basic research are more likely to develop quickly in countries with these kinds of public science systems and labour markets than in those with centralised and segmented ones.

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