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First Author: Fred Block

Corr. Author: Fred Block

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Where do innovations come from? Transformations in the US economy, 1970–2006

Fred Block* and Matthew R. Keller

Department of Sociology, University of California, Davis, CA, USA

**Correspondence: flblock@ucdavis.edu*

This article seeks to reconnect to scholarship from the 1970s and 1980s that emphasized significant discontinuities in the development of the US economy. Drawing on a unique data set of prize-winning innovations between 1971 and 2006, we document three key changes in the US economy. The first is an expanding role of inter-organizational collaborations in producing award-winning innovations. The second is the diminishing role of the largest corporations as sources of innovation. The third is the expanded role of public institutions and public funding in the innovation process. This leads us to the surprising conclusion that the USA increasingly resembles a Developmental Network State in which government initiatives are critical in overcoming network failures and in providing critical funding for the innovation process.

Keywords: capitalism, varieties of, innovation
JEL classification: O31 technological change, research and development – innovation and invention: processes and incentives, O32 management of technological innovation and R&D

1. Introduction

In the 1970s, there was a lively debate on both sides of the Atlantic about basic discontinuities in the development of advanced market societies. A wide range of scholars argued that post-industrial trends would require major institutional reconfigurations in order to secure continuing economic growth (Touraine, 1971; Bell, 1973; Brick, 2006). Parallel arguments were made by theorists of Kondratieff waves (Mandel, 1980) and by contributors to 'regulation theory' (Aglietta, 1979).[1] These arguments continued into the next decade as well, as

[1]The 'Social Structures of Accumulation' approach was similar, but it began slightly later with the publication of Gordon *et al.* (1982).

reflected in the wide interest generated by Piore and Sabel's *Second Industrial Divide* (1984).

However, in the 1990s and 2000s, this debate over discontinuity and institutional reconfiguration largely receded from view.[2] With the renewed ascendancy of 'free market' economic ideas in the policy arena, academic analysts of market societies focused their attention on the strengths and weaknesses of the different varieties of capitalism (Couch and Streeck, 1997; Hollingsworth and Boyer, 1997). Much of the resulting literature focused on continuities in different national trajectories, and work on major developmental discontinuities was de-emphasized. To be sure, some scholars had been arguing that the unchecked growth of global financial activity was creating dangerous instabilities (Block, 1996; Arrighi, 2007), but it was rare for analysts to link financialization to underlying structural weaknesses or developmental barriers in national economies. For this reason, it is safe to say that the eruption in 2008–2009 of the worst global economic crisis since the 1930s took much of the scholarly community by surprise.

This paper is an attempt to reconnect to these older debates about structural transformations in the US economy. Its core argument is that over the same period 1980–2006, when free market ideas have been hegemonic, there has been an acceleration in the post-industrial trends that Daniel Bell and others identified in the 1970s. Most specifically, the centrality of scientific advances to economic production has increased markedly and this has produced significant changes in the organization of business and in the ways that government interacts with business.

Some of these trends have been documented in recent scholarship (Slaughter and Rhoades, 2002; Etzkowitz, 2003; Tassey, 2007; Block, 2008), but knowledge of the key findings has been largely limited to academic specialists. This paper adds new evidence from a unique data set that dramatizes some of the shifts that have occurred over the past 35 years. The data set is a sample of key innovations in the US economy drawn from an annual awards competition for innovative products organized by *R&D Magazine* between 1971 and 2006. Since the production of innovations is a major marker of post-industrial change, this data set provides a useful window into larger processes of economic restructuring.

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[2]To be sure, some work in these different intellectual traditions continues (Block, 1990; Kotz *et al.*, 1994; Boyer and Saillard, 2002; Wallerstein, 2004) but this scholarship of discontinuity has received relatively little attention beyond expert communities. There were also some exceptions to the general trend; Manuel Castells (1996) continued an active dialogue with earlier work on post-industrialism.

2. Reviewing the literature

In *The Coming of Post-Industrial Society*, Daniel Bell provided the most systematic elaboration of the post-industrial concept. In his analysis, post-industrial change is driven by the systematic harnessing by both business and government of science and technology to expand and continuously update the production of goods and services. For Bell, the rise of the computer industry in the 1950s and 1960s with its armies of skilled technologists was a paradigmatic case of this broader process of transformation. Bell anticipated that the growing dependence of business on scientists, engineers and technicians would necessitate larger shifts in business organization and in the role of government.

Bell also anticipated that scientists and engineers would transform both products and processes across the full range of industries in much the same way that industrial technologies diffused across all sectors of the economy over the 19th Century. Craft knowledge and traditional production techniques would give way to sophisticated science-based approaches that enhanced efficiency and created a cornucopia of new goods and services. 'This new fusion of science with innovation, and the possibility of systematic and organized technological growth, is one of the underpinnings of the post-industrial society' (Bell, 1973, p. 197).

Bell foresaw significant changes in the corporation as scientists, engineers and **Q2** other members of a 'new intelligentsia' rose in importance:

> If the dominant figures of the past hundred years have been the entrepreneur, the businessman, and the industrial executive, the 'new men' are the scientists, the mathematicians, the economists, and the engineers of the new intellectual technology. (p. 344)

The argument pointed both to the growing role that technical experts would play in top management positions and to structural changes in the organization of firms. While Bell did not address the issue explicitly, his argument paralleled those of Burns and Stalker (1961) and Bennis and Slater (1968), who argued that the growing centrality of technological expertise would push organizations to be both less authoritarian and less hierarchical, moving from steeper to flatter organizations with greater emphasis on co-ordination by multi-disciplinary teams.

Bell was even bolder in arguing that post-industrial change would transform the relationship between business and government. On the one side, government's dominant role in financing scientific and technological research greatly enhanced its role in the economy. On the other, Bell argued that corporations would have to move beyond narrow profit-maximizing strategies if they were to take full advantage of the new technological possibilities. Hence, he foresaw a new balance of power between business and government:

> It seems clear to me that, today, we in America are moving away from a society based on a private-enterprise market system toward one in which the most important economic decisions will be made at the political level, in terms of consciously defined 'goals' and 'priorities'. (Bell, 1973, pp. 297–298)

Although Bell's framework is now infrequently referenced (see, however, Block, 1990; Brick, 2006), several currents of research have followed up on these arguments. A growing body of scholarly work over the last two decades focuses on 'national systems of innovation' to track how different societies organize the complex task of linking scientific research with product and process innovations (Lundvall, 1992; Nelson, 1993; Collins, 2004). This literature rests on the idea that innovation capacity is centrally important as nations seek to gain advantage in the world economy.

Many of these studies of innovation systems focus on the interface between the public and private sectors, looking particularly at public funding of research and higher education, the growth of the scientific and technical labour force, the systems for establishing and protecting intellectual property rights for innovators and the mechanisms that facilitate the movement of ideas from the research lab- **Q3** oratory to the market. The great strength of this literature is that it looks simultaneously at the role of government and the role of business and raises important questions about the interaction between the two. Nevertheless, this work has identified an important focus of inquiry, but it has not yet identified systematic and causally significant variations in the organization of innovation systems across nations.

A second relevant body of work consists of studies that analyse the shift of business firms, particularly in the USA, towards networked forms of organization. This shift represents a reversal of a pattern of corporate development that started in the last years of the 19th century. Back then, successful US firms aspired to a high level of vertical integration, which meant controlling many different stages of the production process under one corporate roof (Fligstein, 1990). Some of these firms attained high levels of self-sufficiency, often financing their growth with retained profits and drawing much of their technology from their own research laboratories. However, with gathering speed over the last half century, there has been a significant shift in the dominant business model away from vertical integration (Castells, 1996; Powell, 2001).

Many firms have shifted key parts of the production process to supplier firms. The trend is exemplified both by Nike, which has outsourced the production of its athletic shoes, and the increased reliance of Detroit automakers on subcontractors to produce many key parts of their automobiles (Whitford, 2005); but the pattern also extends to the research and development function where many firms are less reliant on their own laboratories and more involved in complex webs of collaboration with other firms, universities and government laboratories (Hounshell, 1996; Powell, 2001; Mowery, 2009).

Implicit in much of the literature on networked firms is the idea that there will be much more fluidity than in a world of vertically integrated firms. New firms will continue to form as a result of spin-offs from existing firms and from university and government laboratories. Moreover, some of these newcomers will be able to exploit their initial role as subcontractors to establish superiority in important new technologies in the way that Microsoft gained strategic control over the operating system for IBM's personal computers. Similarly, large established firms are at risk of precipitous decline if they fail to remain at the frontier of innovation. This gives us our first research question: over the last four decades, has there been a decline in the role of the largest firms as developers of innovative new technologies, or have the largest firms continued to serve as the central nodes of innovation networks?

The rise of a networked industrial structure is particularly obvious in the computer industry and in biotechnology (Saxenian, 1994; Powell *et al.*, 2005). In both industries, small and large firms are involved in elaborate collaborative networks, and it is widely recognized that innovation grows out of processes of co-operation that cross organizational lines; but research to date has been unclear as to whether this pattern of inter-organizational collaboration is characteristic of the entire economy or confined to the most technologically dynamic sectors. Our second research question is whether or not the shift towards inter-organizational collaboration in the innovation process has been a general trend across the entire economy.

A final body of literature has documented the emergence of a triple helix of intertwined efforts by government, universities and corporations to produce more rapid innovation. Extending Bell's analysis, this body of work shows how tightly university-based science efforts are now linked to industry, but it also shows that government agencies are playing an increasingly central role in managing and facilitating the process of technological development (Kenney, 1986; Etzkowitz, 2003; Block, 2008; Geiger and Sa, 2008). In cases such as the Human Genome Project, organized by NIH and the Department of Energy, and the Strategic Computing Initiative organized by DARPA, government officials have played a central role in both setting technological goals and providing the funding to facilitate joint efforts by university-based researchers and business (Kevles, 1992; Roland and Shiman, 2002; McCray, 2009).

These targeted government programmes have been combined with a highly decentralized system for encouraging innovation. Starting in the 1980s, new incentives were created for publicly funded researchers at universities and government laboratories to pursue commercial applications of their discoveries. Such efforts have been supported by funding programmes, such as the Small Business Innovation Research (SBIR) programme through which government agencies set aside a small percentage of their R&D budgets for projects proposed by small firms, many of which are newly created spin-offs from university or federal laboratories (Wessner, 2008). Other programmes have been created to encourage joint ventures between researchers in university and federal laboratories and business firms (Block, 2008; Geiger and Sa, 2008). This provides us with our third research question: has there been a marked increase in the public sector's role in funding and facilitating innovation efforts?

Exploring each of these questions requires finding some way to measure innovative activities. However, the measurement of innovation has been a longstanding problem for social scientists. It is not adequate to count the dollars spent on research and development or the number of scientists and technologists at work since these are simply inputs to the innovation process. Many studies have used patent statistics as a proxy, but these are unreliable because of variations in the quality of patents and in the criteria that are used to approve patent applications (Sciberras, 1986; Taylor, 2004).

In this paper, we use a data set of award-winning innovations to illuminate structural shifts in the US economy that have occurred over the last four decades. Our aim is to show that the developmental discontinuities predicted by post-industrial theory have, in fact, happened, but they have not been accompanied by the kind of political reconfigurations that Bell and others anticipated.

3. Introducing the data

For more than 40 years, *R&D Magazine* has annually recognized 100 innovations that are incorporated into actual commercial products. These awards are comparable to the Oscars for the motion picture industry; they carry considerable prestige within the community of research and development professionals. Organizations nominate their own innovations and a changing jury that includes representatives from business, government and universities, in collaboration with the magazine's editors, decide upon the final list of awards.[3] The awards go to commercial products that were introduced into the marketplace during the previous year. The entry forms require evidence of the availability of the product and its price. With 100 innovations that can be recognized, juries are able to recognize

[3]The nomination and selection procedures are described on the magazine's website at http://www.rdmag.com/100win.html.

the full diversity of innovative products, not just to focus on dynamic sectors such as electronics or biotechnology.

We coded all of the winning innovations for three randomly chosen years in each of the last four decades to identify the types of organizations that were responsible for nurturing the award winners. (Full data are provided in Table 1.) Since 1971, somewhere between 5 and 13 of the awards each year went to foreign firms that had no US partners.[4] We excluded those cases and focused our analysis on the roughly ninety award winners each year that involved US-based firms.

While the awards recognize innovations in a wide range of different industries, there are some biases in the process. The awards are tilted towards product innovations rather than process innovations – those that are designed to raise the efficiency of the production process for goods and services. Some process innovations, such as a new type of machine tool or a more advanced computer program for managing inventories, are recognized, but many important process innovations are not considered because they involve complex combinations of new equipment and new organizational practices. Many military innovations are also excluded, since cutting-edge weapons are usually shrouded in secrecy and unavailable for purchase. Since the great bulk of federal R&D dollars are still directed towards weapons systems, many government funded innovations lie outside of this competition.

Furthermore, the awards are structured to recognize just the tip of the proverbial iceberg – the last steps in the innovation process. The many earlier steps are submerged and out of sight. This bias means that the awards understate the role of university-based research since detailed case studies suggest that many key innovations can be traced back to scientific breakthroughs in university laboratories (Roessner *et al.*, 1997).

What other biases might enter the awards process? Questionable decisions and politics will always be a factor as jury members seek to reward friends and deny recognition to enemies. Nevertheless, for our purposes, it is not necessary that these awards recognize *the very best* innovations of any particular year. All that is necessary is that the awardees represent a reasonable cross section of innovative products and that there is not a consistent bias that favours awardees of a particular type.

Different resources that organizations have to prepare their nomination materials are another potential source of bias in competitions. Big architectural firms, for example, can hire the best photographers and devote considerable resources to a nomination while the hard-pressed solo practitioner might

[4]The only exceptions occur when a foreign firm owns a large, established US business, such as when Chrysler was owned by Daimler Benz. In such cases, we code the firm as a Fortune 500 firm.

Table 1 Composition of *R&D 100* award winners

	1971	1975	1979	1982	1984	1988	1991	1995	1997	2002	2004	2006
Total awards	102	98	100	100	100	100	98	101	100	97	94	100
Total foreign	5	12	10	14	14	11	13	12	12	14	10	12
Total domestic	97	86	90	86	86	89	85	89	88	83	84	88
Of domestic award winners†												
Private												
1. Fortune 500 alone	38	40	29	37	26	14	9	11	7	5	5	2
2. Other firms alone	42	25	28	18	23	18	20	20	15	34	24	20
3. Private consortia	3	8	6	4	3	5	4	7	3	11	1	5
Includes F-500 firm	1	2	4	3	1	4	1	4	1	7	1	0
Sub-total	83	73	63	59	52	37	33	38	25	50	30	27
Public or quasi-public												
4. Supported spin-offs	4	1	2	1	1	5	4	5	8	4	8	11
5. Government labs	4	8	15	15	24	38	44‡	38	42	26	38	42
Solo credit	1	2	10	15	18	25	28	25	11	7	16	23
w/F-500	1	5	2	0	3	4	4	3	5	1	2	3
w/university	0	0	0	0	1	2	4	2	3	2	5	7
w/others	2	1	3	0	2	7	9	8	23	16	15	9
6. Universities	3	0	4	4	1	1	1	5	6	2	4	2
Solo credit	1	0	4	1	1	1	1	1	2	0	1	0
w/F-500	1	0	0	0	0	0	0	0	0	0	0	0
w/others	1	0	0	3	0	0	0	4	4	2	3	2
7. Other public	3	4	6	7	8	8	3	3	7	1	4	6
w/F-500	0	0	0	1	1	0	0	0	2	0	1	1
Sub-total	14	13	27	27	34	52	52	51	63	33	54	61
Total F-500	41	47	35	41	31	22	14	18	15	13	9	6

Notes: †As noted, if a single firm won multiple *R&D 100* awards in a given year, it is counted one time for each award.
‡The number of sub-categorizations exceeds 44 because one collaboration involved both a Fortune 500 firm and a university.

throw the application form together in a few hours (Larson, 1993, 1994). There is probably a similar bias in these awards with larger organizations having more expertise at putting together persuasive nomination packets.

However, there are reasons to think that the magnitude of this bias would be limited. For one thing, the universe of applicants is limited to organizations that have actually developed a commercial product, and since winning the award is a powerful form of advertising, even the tiniest firms have strong incentives to devote resources to an effective application. For another, the quality of 'coolness' that engineers and technologists admire in a product is substantially easier to convey in words than the more abstract, aesthetic qualities that architectural or film juries might be rewarding. Finally, over the years there are many one-time winners, which reinforces the impression that it is the quality of the product and not the quality of the nomination packet that wins awards.

There are, however, two distinct biases in the awards that are important for interpreting our results. First, it is very rare for the *R&D 100* awards to recognize new pharmaceutical products. While there are many awards for medical devices and equipment, there seems to be a deliberate decision to avoid medications of all kinds. Our assumption is that this reflects an abundance of caution by the magazine, which does not want the bad publicity or legal liability of recognizing a product that might later be found to have negative side effects.

A second exclusion is more surprising. There are few awards over the last 20 years for products – either hardware or software – developed by the largest computer firms. Apple did not win an award for the iPod, Microsoft has received only one R&D award since it began and firms such as Intel, Sun Microsystems and Cisco have each won only once. Many of the products of this industry represent incremental improvements such as new versions of software packages or slightly improved notebook computers and it is logical that the jurors ignore these; it also seems likely that even when they produce a more dramatic innovation, the jurors hold them to standards higher than those used for other organizations.

While these two exclusions indicate the need for caution in interpreting the results, they are analytically fortuitous. Since the data largely leave out big firms in the two industries – biotechnology and computing – that are generally seen as paradigmatic examples of science-based production, strong network ties among firms and substantial governmental involvement in the innovation process, the awards data allows us to take a broader view of the innovation economy. To what degree are the same trends affecting sectors that have not been as strongly associated with science-based production?

3.1 Coding

It would be ideal to code both the organizational auspices and the funding sources for every innovation awarded in the 12 competitions that we analyse; but while the organizational auspices can be established with a reasonable amount of research, uncovering the funding sources for almost 1200 different innovations is an almost impossible task. The primary difficulty is that tracking flows of federal support to businesses is laborious and complicated.[5] In our data, we coded the organizational auspices as completely as possible for the roughly 1200 innovations. Our approach to establishing the funding sources of the recognized innovations represents a compromise. We performed a detailed analysis of federal funding to award-winning firms and innovations for the years 1975 and 2006 to maximize the contrast across time.

In organizational terms, the data revealed seven distinct loci from which the award-winning innovations originated. They are:

Private:

(1) Fortune 500 firms operating alone.

(2) Other firms operating on their own; this is a residual category that includes small- and medium-sized firms.

(3) Collaborations among two or more private firms with no listed public sector or non-profit partner. Industrial consortia are included in this category.[6]

Public or mixed:

(4) Supported spin-offs. These are recently established (less than 10 years from founding) firms started by technologists at universities or government laboratories who have been supported by federal research funds.

(5) Government laboratories – working by themselves or in collaboration. Most of these innovations come from the federal laboratories run by the

[5]This paper neglects in-kind government support which is an increasingly important factor in technology policy. For instance, in 2006, the Department of Energy, which runs many of the large government laboratories, reported that there had been 2416 active arrangements where DOE laboratories did work for others with some partial compensation and 3474 user agreements where firms were allowed to use laboratory equipment. Unfortunately, the DOE does not publish the names of the firms that benefit from this assistance.

[6]We list any innovation as public as long as there is a collaborator that is public or a supported spin-off. We avoid double counting by listing collaborative winners under just one of these categories. If a government laboratory is a participant in a collaboration, the innovation is attributed to the laboratory regardless of other participants. If no government laboratory is involved, but there is a university, then the innovation is attributed to the university. If there is another public or non-profit participant, the innovation is attributed to that participant. If there are multiple private participants, then it is coded in category 3 – private collaboration. Table 1 in the Appendix provides sufficient detail to show that this particular coding scheme does not bias our results.

Department of Energy, but some come from NIH, military laboratories and laboratories run by other agencies. If a university is a partner in one of these collaborations with a laboratory, it will be reported here and not under university.

(6) Universities – working by themselves or in collaboration with entities other than federal laboratories.

(7) Other public sector and non-profit agencies – working by themselves or in collaboration with private firms.

4. Analysing the data

The R&D awards data provide powerful evidence on all three research questions. We start with the second question – whether the shift towards collaboration has become a general trend. Analysts of the networked firm have argued that innovation increasingly results from collaborations between two or more organizations (Hargadon, 2003; Lester and Piore, 2004). The connections between knowledge embodied in one organization and the knowledge embodied in other organizations are critical for the innovation process. The sparks generated when these different approaches are combined facilitate the discovery of effective new approaches (Hargadon, 2003). Our data provide support for this claim. Figure 1 shows a dramatic rise in the number of domestic award-winning innovations that involve inter-organizational collaborations. The number of innovations attributed to a single private sector firm operating alone averaged 67 in the 1970s, but that has dropped to an average of only 27 in the current decade.

In part this shift reflects the growing importance of public sector agencies as award winners, since we code all public agencies as engaging in collaboration since they invariably employ private partners to market their innovative products. Nevertheless, it is also the case that even among the dwindling number of private **Q4**

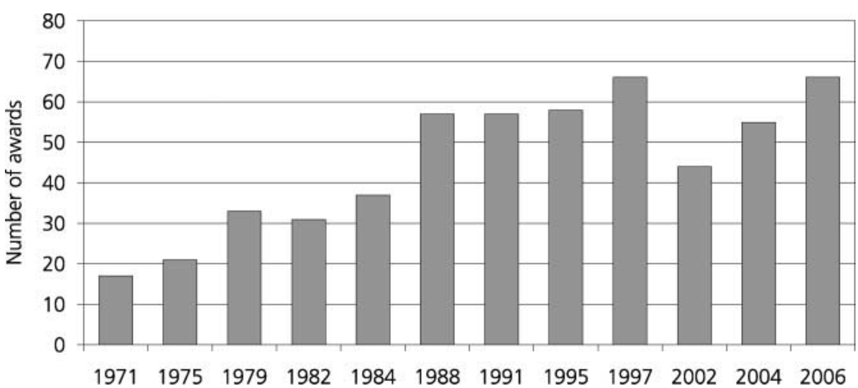

Figure 1 R&D 100 awards to inter-organizational collaborations.

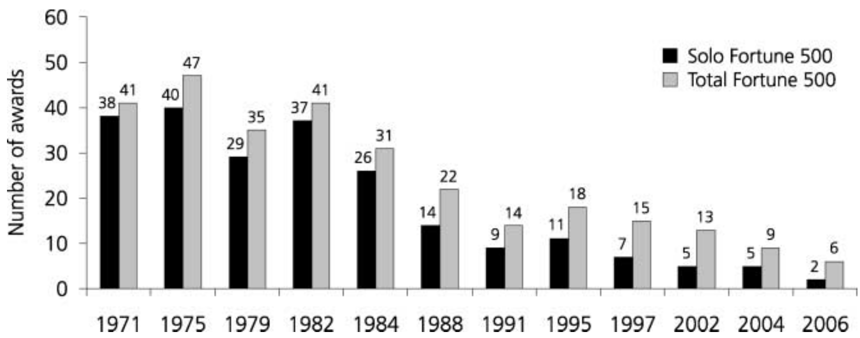

Figure 2 R&D 100 award winners from the Fortune 500.

sector winners, the frequency of formal collaborations rose from 7.8% in the 1970s to 17.5% in the current decade.

An equally striking finding addresses the first research question – the role of large corporations in the innovation process. Figure 2 shows the dramatic decline in both solo and collaborative winners from the Fortune 500 firms. While these firms were the largest single winner of awards in the 1970s, by the current decade, solo winners from the Fortune 500 could be counted on the fingers of one hand. Even with collaborators, they averaged only 10 awards per year.

To be sure, this is the place where the almost total exclusion of large computer industry firms and pharmaceutical firms impacts the data. Data on US patent applications shows that firms such as IBM, Microsoft, Intel and Sun rank among the most prolific US firms in the number of patents received (US Patent and Trademark Office: http://www.uspto.gov/web/offices/ac/ido/oeip/taf/reports.htm). They also represent important exceptions to the tendency for big firms to reduce their outlays for R&D over the past 20 years. Hence the fact that their R&D effort is only rarely recognized in the *R&D 100* means that Figure 2 overstates the declining innovative capacity of Fortune 500 firms. However, even if the large computer industry firms were collectively receiving 10 of these awards per year, Figure 2 would still show a significant downward trend.

The situation with pharmaceutical firms is more complicated. While the established large firms such as Merck and Pfizer and the most successful of the biotech firms such as Genentech and Amgen continue to fund significant research efforts, the number of innovative drugs they bring to the market in recent years has been quite limited. The drug industry has its own awards for innovation published by *Prescrire International* (2007).[7] Their highest award, the golden pill, recognizes new drugs that represent a major breakthrough; but between 1997 and 2006,

[7]We are grateful to Donald Light for bringing these awards to our attention.

only two drugs received this recognition and there were only 12 others that received second place recognition as a clear advance over existing therapies. This suggests that if the *R&D 100* competition had recognized prescription drugs, the results in Figure 2 would not have changed much at all.

The real significance of Figure 2 is the decline in awards won by general purpose manufacturing firms such as General Electric, General Motors and 3M. Firms like these dominated the awards in the 1970s, but they only rarely win in recent years. This decline parallels the trend in their patenting activity, strongly suggesting diminished innovative efforts. Figure 3 shows a dramatic decline in the percentage of US corporate patents won by nine of these manufacturing firms that have been in continuous existence and are outside the computer industry.

These declines can be traced to the priorities of corporate executives faced with continuing pressure over the last several decades to improve the quarterly financial results of their firms. Many firms have cut back their R&D efforts or shifted funds towards product development. After all, research is expensive and its contribution to the bottom line is likely to come long after the current CEO's tenure in office. At the same time, the financial orientation of top executives means that they see new technologies as simply another asset that can be acquired rather than produced internally. They are confident that when the time comes, they can either license the technologies they need or buy up the firms that are producing innovations (Tassey, 2007; Estrin, 2009).

The magnitude of this shift is indicated by employment trends among scientists and engineers working for private firms. According to data collected by the NSF, in 1971 7.6% of R&D scientists and engineers working for industry, or 28 200 individuals, were employed by firms with fewer than 1000 employees. By 2004, this percentage had risen to 32%, while the actual number of people had grown to 365 000. NSF data also indicate that PhD scientists and engineers have become even more concentrated in small firms; in 2003, 24% of those working for industry were employed at firms with fewer than 10 employees and more than half were at firms with under 500 employees.[8] It is, of course, impossible to know how much of this shift reflected push factors that led technologists to leave large firms and how much was the attraction of working in smaller firms. Either way, the trend in the awards away from big firms follows the trend of the technologists who create the innovations.

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[8]'Number of full-time-equivalent R&D scientists and engineers in R&D-performing companies, by industry and by size of company' is available at http://www.nsf.gov/statistics/iris/search_hist.cfm?indx=24 and http://www.nsf.gov/statistics/nsf07314/pdf/tab41.pdf. These figures should be taken as approximations due to changes in NSF's procedures for collecting and estimating this data over time. Data on PhD employees are provided in figure 3.18 in Science and Engineering Indicators, 2008 at http://www.nsf.gov/statistics/seind08/figures.htm.

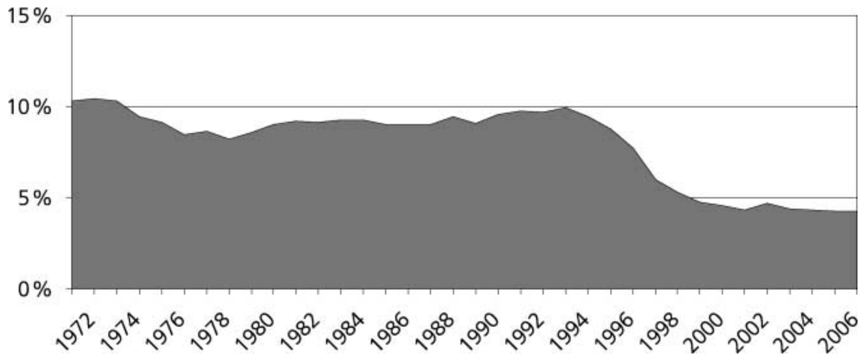

Figure 3 Percent of total US corporate patents received by GE, Kodak, AT&T, DuPont, GM, Dow Chemical, 3M, United Technologies and Ford, 1971–2006. *Source*: US patent and trademark office data.

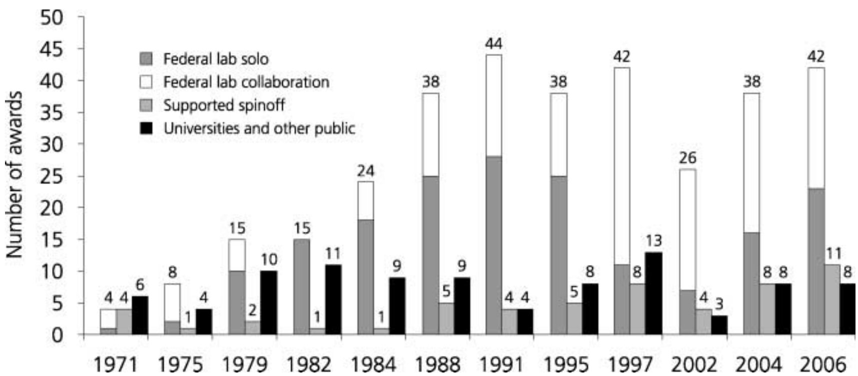

Figure 4 Awards to federal labs, supported spin-offs and other public entities.

As the role of large corporations declined, there has been a corresponding gain in awards for public and mixed entities. This provides answers to the third research question – whether the public sector is playing an expanding role in the innovation system. As Figure 4 shows, the majority of awards are now won by either federal laboratories, universities or the firms that we have categorized as supported spin-offs. In the last two decades, the federal laboratories have become the dominant organizational locus for wining these awards. They now have about the same weight in the overall awards as the Fortune 500 firms did in the 1970s – averaging about 35 awards per year.[9] This is a surprising finding because many observers hold the federal laboratories in low esteem and doubt their capacity to contribute

[9]In the cases that we have coded as solo, the innovation award went solely to a federal laboratory or a university. This presumably indicates that the partner enlisted to commercialize the product had no ownership of the intellectual property involved in the innovation.

to innovation. Most of the winning innovations originate in the Department of Energy laboratories that were initially created to develop atomic weapons in the early years of the Cold War. The sinister image of PhD physicists and chemists working assiduously to develop ever more destructive weaponry has certainly coloured the public image of these facilities.[10]

After the Federal laboratories, the next most important public or mixed entities are the supported spin-offs. These entities – on their own – averaged close to eight awards per year in the current decade and they also have won some additional awards in partnership with government laboratories or universities. Moreover, as we shall see later, firms that began as supported spin-offs but have been in existence for more than10 years are coded as 'other firms' – part of the private category – and their weight in the awards has also increased over time.

The typical pattern of a supported spin-off is that a professor or a scientist at a university or federal laboratory makes an important discovery and consults with university or laboratory officials as to how best to protect the resulting intellectual property. In many cases, the organization encourages the innovator to start his or her own firm to develop and ultimately market the new product. The more entrepreneurial universities and laboratories function almost as venture capitalists by helping the individual find investors and experienced managers who could guide the firm (Geiger and Sa, 2008).

The final category in Figure 4 encompasses awards won by universities and other public sector agencies and non-profit firms. Surprisingly, the direct weight of universities among award winners is relatively modest. There are several reasons for this. First, some innovations that originate in university laboratories show up in the supported spin-offs category because the researcher started his or her own firm. Second, university-based researchers are increasingly part of collaborations with federal laboratories and our coding system attributes those innovations to the laboratories. In 2006, for example, universities received two awards in partnership with other firms and seven in partnership with federal laboratories. In short, even though the importance of scientific discoveries at universities has become ever more central to the innovation process, most of the transition into commercial products is mediated through spin-offs and the activities at federal laboratories.[11]

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[10]Even in the scholarly literature, it is rare to find recognition of the innovation productivity of the laboratories. For an overview of the laboratories (see Crow and Bozeman, 1998). One of the rare sources that recognizes the increased commercial productivity of the laboratories is Jaffe and Lerner (2001).

[11]Even if we recode collaborations that involve both a federal laboratory and a university as 'university', the number of award-winning innovations involving federal laboratories still substantially outweighs those involving universities.

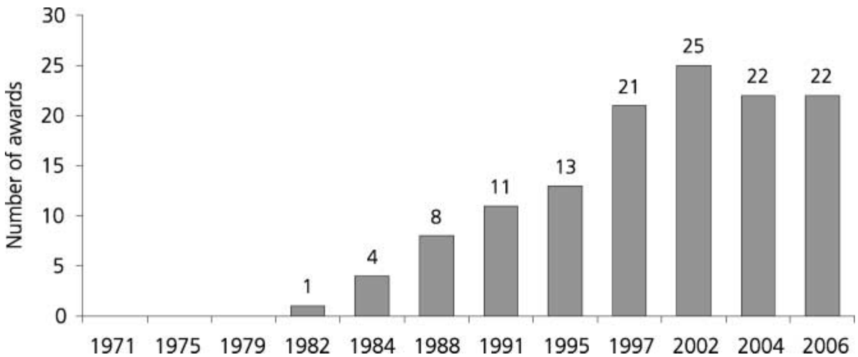

Figure 5 Awards to SBIR-funded firms. *Note*: The single firm listed in 1982, Radiation Monitoring Devices, received funding from the SBIR precursor program, a pilot project operated under the auspices of NSF.

Nevertheless, a focus on organizational auspices alone does not capture the full extent of US government financing of the innovation process. Figure 5 shows the role of one of the most important – but little known – federal programmes: the SBIR programme. Firms that had ever been winners of an SBIR award represent a very large share of winners in the current decade. SBIR is a set aside programme which requires that federal agencies with large research budgets devote 2.5% of their R&D budgets to support firms with 500 employees or less. It is also a programme that provided initial funding for many of the supported spin-offs. The programme awards up to $100 000 in no strings support for projects in Phase I and up to $750 000 for Phase II projects that have shown significant progress in meeting the initial objectives.[12] In 2004, the SBIR project gave out more than $2 billion for some 6300 separate research projects. As the figure shows, current and past SBIR award winners have come to constitute roughly 25% of domestic winners each year.

In Figure 6, we try to provide a more comprehensive measure of the role of federal financing over time by looking in greater detail at funding for award winners in 1975 and 2006. The bottom part of each graph shows the various public sector winners that rely heavily on federal funding. As indicated earlier, this shows a dramatic rise from 14 to 61 of the awardees. However, the top part of the graph shows the number of 'other' and Fortune 500 firms that received at least 1% of their revenues from the federal government.[13] This 1% screen picks up both large defence contractors as well as firms that have received substantial

[12]The NIH has applied for and received a waiver which enables it to exceed these caps.

[13]The logic of using a 1% of revenue screen is that it is common among large firms to devote only 3-4% of revenues to R&D expenditures. Hence federal awards or contracts of that magnitude could help fund a significant increase in R&D effort.

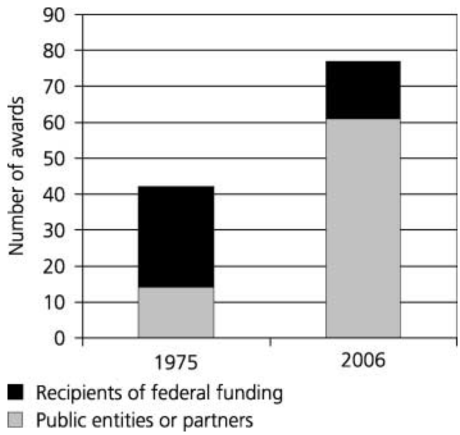

Figure 6 Federal involvement with award-winning innovations, 1975 and 2006.

federal grants to support their R&D efforts. In 1975, there were 23 awards won by private firms who received at least 1% of their revenues from federal support. Prominent among these was general electric which in that year was responsible for nine award-winning innovations.[14]

In 2006, we found that of five private collaborations, the federal government directly funded three. Of the 20 'other firms' that won awards, 13 had federal support above the 1% threshold *and* we were able to link the federal money directly to the specific innovation that received the award. Hence, 16 of these 'private' innovations count as federally funded. The overall result in Figure 6 is that the number of federally funded innovations rises from 36 in 1975 to 77 in 2006.

In 2006, literally only 11 of the domestic award winners were *not* beneficiaries of federal funding. Two winning firms – Brion Tech and MMR Technologies – were recent spin-offs from Stanford University, but they had not received federal funding after their launch. In short, Figure 6 probably understates the magnitude of the expansion in federal funding for innovations between 1975 and 2006. After all, in 1975, we count innovations as federally funded even if support was not going to the specific unit of the firm that was working on a particular innovation. For 2006, however, a demonstration of federal support required showing that the federal funds were going to the same unit that was responsible for the particular technology that won the award.

Even during the period that Fortune 500 corporations dominated the innovation process, they drew heavily on federal funding support. If one is looking for a golden age in which the private sector did most of the innovating on its

[14]There were five additional awards that went to Fortune 500 companies that had contracts to manage government laboratories in 1975 – two each for Union Carbide and DuPont and one for Monsanto.

own without federal help, one has to go back to the era before World War II (Hounshell, 1996). Nevertheless, over the last 40 years, the awards indicate a dramatic increase in the federal government's centrality to the innovation economy. In the earlier period, US industrial and technology policies were almost entirely monopolized by the military and space programmes (Hooks, 1990; Alic, 2007). More recently, a wide range of non-defence agencies are involved in supporting private sector research and development initiatives. Key agencies now include Commerce, Energy, NIH, Agriculture, NSF and Homeland Security.

5. Discussion

Our data set provides evidence of three interrelated changes in the US economy over the past generation. These are the declining centrality of the largest corporations to the innovation process in the USA, the growing importance of inter-organizational collaboration and small start-up firms in the innovation process, and the expanded role of public sector institutions as both participants in and funders of the innovation process.

It is the last of these shifts that is the most surprising since this change coincided with the period in which market fundamentalist ideas dominated public policy debates; but it is important to recognize how different the federal role is from models of centrally planned technological change. In Chalmers Johnson's (1982) classic account of the Japanese model of industrial policy, he shows how government officials, working at the Ministry of Trade and Industry, operated as both co-ordinators and financiers for the conquest by Japanese firms of new markets. The key was that the government officials were implementing a shared plan that linked investments in particular technologies with specific business strategies to win in particular markets – both domestically and internationally.

In the US case, there is no unified plan and different government agencies engage in support for new technologies often in direct competition with other agencies. The approach is more like Mao's 'let a hundred flowers bloom': the USA has created a decentralized network of publicly funded laboratories where technologists have strong incentives to work with private firms and find ways to turn their discoveries into commercial products. Moreover, an alphabet soup of different programmes provides agencies with opportunities to help fund some of these more compelling technological possibilities.

Alongside this 'build it and they will come' approach, there are also targeted government programmes that are designed to accelerate progress across specific technological barriers. However, these programmes are also implemented in a decentralized fashion by small agencies. The model developed by DARPA of setting technological goals and working closely with researchers to accelerate breakthroughs has now diffused across the federal system (Block, 2008).

Nevertheless, because these programmes contradict the market fundamentalist ideology that celebrates private enterprise and denigrates the public sector, they have remained largely unknown to the public. Journalists rarely write about government technology initiatives; for example, *The New York Times* has mentioned the SBIR programme in its news coverage fewer than10 times over the last 27 years. To be sure, Congress periodically debates the design and funding for these programmes, but reports on these discussions are rarely covered in *The Wall Street Journal* or general purpose business publications. Since the programmes are largely unknown, they simply do not figure in public policy debates (Block, 2008).

Ironically, the parameters of these little known state programmes fit the model of a Developmental Network State (DNS) that Sean Ó Riain (2004) elaborated in his study of the Irish government's efforts to encourage high-tech growth in that nation (see also Breznitz, 2007). Just as in Ó Riain's case, government efforts are highly decentralized, rely on strengthening technological networks that cut across the public–private divide and require public sector officials to play a multiplicity of roles in supporting entrepreneurial efforts.

Recently, Whitford and Schrank (2009, forthcoming) have usefully conceptualized these government programmes as efforts to overcome failures that are endemic in networked forms of economic organization. In contrast to market failures, network failures occur when economic actors are unable to find appropriate network partners who are both competent and trustworthy.

The programmes of a DNS help to stitch together networks and work to improve and validate the competence of potential network partners. Furthermore, the federal laboratories, industry–university research centres sponsored by the NSF and informal meetings sponsored by agencies such as DARPA create 'collaborative public spaces' (Lester and Piore, 2004) where network participants are able to share key ideas.

However, the DNS also addresses a classic market failure – the difficulty of funding early stage technologies. While private sector venture capital has gained wide attention, the reality is that most VC investments go to companies that already have developed a commercial product (Branscomb and Auerswald, 2002; Gompers and Lerner, 2004).[15] Government agencies have moved into this gap and they self-consciously use a venture capital model in which 20 separate initiatives are financed with the idea that only a fraction will achieve significant breakthroughs that more than cover the costs of the failures.

[15]Price Waterhouse Coopers provides a database that shows trends in private venture capital financing both in terms of dollars and number of deals (https://www.pwcmoneytree.com/MTPublic/ns/index.jsp). In 2005, for example, private venture capital financed 1061 firms at start-up or at early stages with a total of $4.7 billion. Since these cover the entire US economy, these are quite small numbers.

The SBIR programme fits this model. Many of the government agencies were initially resentful of SBIR because it meant that they could not use a portion of their own R&D on their highest priority efforts (Wessner, 2008). However, quite a few of the agencies have come to see SBIR as a valuable mechanism that works better to get the innovations they need than collaborating with large established firms. However, since SBIR support for firms is generally limited to about 3 years for any particular project, a number of government agencies have now set up their own venture capital operations. The CIA's venture capital arm, In-Q-Tel, maintains its own website and lists 90 recent start-up firms in which it has invested. Congress provided a $500 million initial fund, and just as with private sector venture capital, the idea is that the initial fund will be replenished and expanded as In-Q-Tel sells its stake in those firms that have been successful. The Department of the Army has followed the CIA model while the Department of Energy has partnered with Battelle – the large non-profit organization that manages several of the DOE laboratories – which has now created its own not-for-profit venture capital arm with an emphasis on supporting start-up firms that originated in the laboratories (Keller, 2009).

It is too early to tell whether this experiment in public sector venture capital will be expanded; but the fact that such initiatives flourished even during the 'free market' oriented administration of George W. Bush reinforces the point that the USA has changed fundamentally over the past three decades in the direction of smaller technology firms, more complex inter-organizational collaborations and a greater public sector role.

Nevertheless, the critical point is that these post-industrial changes occurred 'behind the back' of both social actors and social scientists; they were not accompanied by any post-industrial awareness or any publicly visible renegotiation of the relationship between state and economy. On the contrary, they coincided with the resurgence of the free market ideas that had been marginalized through the 1940s, 1950s and 1960s (Block, 2007). Moreover, under the reign of market liberalism, the US economy experienced three decades of spectacular growth of the financial sector (Krippner, 2005) – a development that had not been at all anticipated by post-industrial theorists and which also diverted attention and resources from the structural changes documented here.

6. Conclusion

There is a direct connection between the story elaborated here and the global economic crisis of 2008–2009. Despite its considerable accomplishments, the emergent US innovation economy of small- and medium-sized firms working with public institutions has been chronically underfinanced throughout its history. One reason that government agencies, such as the CIA, have launched their own venture capital operations is that flows of private sector venture capital to these smaller technology firms have been woefully insufficient, particularly in the early stages of technology development. The literature describes these firms as struggling to cross 'the valley of death' – a multi-year period in which they attempt to transform technological breakthroughs into commercial products (Branscomb and Auerswald, 2002). Even when venture capital is offered, the terms can be unattractive because ceding control over a start-up's intellectual property and decision-making rights are often the price for an initial investment (Lerner, 1999; Wessner, 2008). Aside from government programmes, there is no systematic mechanism available to direct private capital flows to support these firms in their early stages.

At the same time, the federal government's own spending in support of research and development has fallen from nearly 2% in the mid 1960s to about 0.7% in recent years (American Association for the Advancement of Science 2008 at http://www.aaas.org/spp/rd/usg07.pdf; Tassey 2007). Programmes designed to accelerate the commercialization of new technologies have been forced into a destructive zero sum battle with programmes to support fundamental research, and scientists in different fields have been pitted against each other to win funding. In fact, over a 30 year period of chronic tax cutting, the federal government's total civilian investment spending – on research, on education and on infrastructure – has fallen from 2.7% of GDP to 1.8%. Moreover, public universities have also been hit hard by declining support at the state level (Newfield, 2008).

In short, all parts of this new innovation system have suffered from insufficient financing; yet over the last 20 years, the US economy experienced massive inflows of foreign capital as foreign countries loaned the US money to cover its chronic trade deficit (Bernanke, 2005). In addition, 1arge non-financial corporations in the USA, such as the Fortune 500, have also been net purchasers of financial assets, adding to the pool of savings in search of profitable investment outlets. Many analysts believe that this growing pool of surplus saving was responsible both for the stock market bubble of the 1990s and the disastrous housing bubble of the 2000s, and it was the bursting of the US housing bubble that triggered the global economic downturn.

If capital markets had been structured more effectively, some of that pool of excess saving could have been channelled into financing the US innovation economy in a sustainable fashion, and that might also have worked to strengthen the US balance of trade.[16] One can only speculate as to whether the existence of more productive outlets for capital investment might have attenuated the

[16]To be sure, the Internet bubble of the 1990s channelled vast amounts of capital to high-tech firms in search of quick, speculative profits. The key is to create patient flows of capital to smaller technology firms.

housing bubble. However, looking forwards, there is an urgent need for structural reforms that expand government funding of research, development and higher education and that dramatically increase the availability of long-term, patient finance for the thousands of small- and medium-sized technology firms that are increasingly the productive core of the US economy. Such reforms might also reduce the US economy's vulnerability to destructive financial bubbles.

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