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THE IMPACT OF MILITARY RESEARCH AND DEVELOPMENT PRIORITIES ON THE EVOLUTION OF THE CIVIL ECONOMY IN CAPITALIST STATES

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ABSTRACT

The Impact of Military Research and Development Priorities on the Evolution of the Civil Economy in Capitalist States*

Military priorities influence a significant proportion of the resources that capitalist societies devote to R&D. Such military priorities favour some areas of technological development and the technology developed in these favoured areas often forms the basis of important civil industries. Indeed some of the commanding heights of civil economies have been powerfully shaped by the opportunities created by specifically military R&D. This paper is an attempt to sketch the broadest dimension of 'spin-off' from military R&D to the civil sector, namely the distortion of investment choices that arises from military underwriting of certain kinds of technological development, and to raise some possible questions for research and public policy. We start by looking at the general relationship between military and civil technology, at the different motives that drive innovation in the two sectors, and at the underlying theoretical links between these motives in capitalist societies.

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NON-TECHNICAL SUMMARY

Military priorities influence a significant proportion of the resources that capitalist societies devote to R&D: for the United States in the period 1982-4, military R&D amounted to 28.9% of gross domestic expenditure on R&D. This paper identifies the process by which military research and development (R&D) priorities affect the evolution of major sectors of the civil economy in capitalist states. The nature of military priorities favours some areas of technological development over others, and once these favoured areas are developed for military purposes, it is often possible to build a major civil industry on the resultant technology. Examples of this process include nuclear power, civil aviation, space satellites and computers. Some, though by no means all, of the commanding heights of civil economies are thus powerfully shaped by the opportunities created by specifically military R&D.

This paper sketches a neglected dimension of the 'spin-off' from military R&D to the civil sector, namely the distortion of investment choices that arises from military underwriting of certain kinds of technological development. We begin by looking at the general relationship between military and civil technology, at the different motives that drive innovation in the two sectors, and at some of the underlying theoretical links between these motives in capitalist societies. We also survey the history of this relationship since the early nineteenth century and conclude that the century from 1845 to 1945 can be seen as a period during which states adapted to the military consequences of the apparently permanent process of rapid technological advance. Since 1945, that adaptation has become a permanent, and deeply structured, feature of state behaviour. Finally we examine the consequences of that adaptation for four major civil industries since 1945: nuclear power, space satellites, civil aviation and computers.

We argue that the priorities that shape military R&D have nothing to do with commercial logic. The technological opportunities made available by military R&D can nonetheless greatly alter commercial logic in many sectors of the economy. The sunk costs of military R&D can advance the introduction of an industry by many years, even decades. It seems highly unlikely, for example, that either mass air transport or space satellites would have developed anything like as early as they did if it were not for the fact that military R&D laid massive 'premature' foundations for them. The commercial nuclear power industry might never have developed at all in its current form without the military impetus.

The existence of a large, militarily directed R&D effort thus introduces a substantial distortion into what would otherwise be the 'natural' development of a civil economy shaped by a more purely commercial logic.

In common usage, the term 'military technology' often suggests that military technology is quite distinct from that in the civil sector. But although military technology may pursue some routes peculiar to itself, and may in some sectors serve as the leading edge for developing new capabilities, it is nonetheless closely tied to the general character of civil technology in terms of knowledge and industrial capacity. In crude terms, an economy that can build jet bombers, inter-continental ballistic missiles, tanks and computerized guidance systems can also build jet airliners, satellite launchers, automobiles and personal computers – and vice versa. Both military and civil technology stem from a common stock of scientific and engineering knowledge: the gap between civil and military technology is always quite limited in size when compared with the overall base of knowledge and industrial capability from which both spring.

The underlying closeness of civil and military technology has profound consequences for how one views important phenomena ranging from arms races to surplus productive capacity in many industrial sectors of world trade. In the present context, this inherent closeness underpins, and perhaps even amplifies, an important confluence of interest within capitalist societies in technological innovation for both civil and military purposes. The civil imperative for technological innovation under capitalism links directly to the profit motive. Either by increasing efficiency in existing economic activities or opening up new markets altogether by stimulating new activities, technological innovation provides one of the most attractive sources of profit in a capitalist economy.

The military imperative for technological innovation is quite different in origins from the civil one, though obviously complementary to it. In the anarchic society of sovereign states, each government is responsible for protecting its state against the possibility of military attack by others. Simple prudence requires states to maintain military forces that are in some sense proportional to the military threats that others can bring to bear on them. Military rivalries among industrialized states thus tend systematically to promote the development of military technology. Falling too far behind the prevailing technological standard seriously undermines one's relative military capability. Occupying the leading edge of the prevailing standard conversely offers a security premium.

This confluence of interest in technological innovation, both military and civil, within capitalist states links to the historical association between capitalism and anarchic (i.e. politically fragmented) international systems. Several writers have argued that capitalism only arose in Europe because of the failure of European civilization to achieve political unity on the imperial model of China. Only the relative freedom from central political control created by a multi-state anarchy allowed market behaviour to become a dominant social and economic force. To the extent that this quite widespread historical interpretation is valid, then military and civil technological innovation in capitalist societies go hand in hand: indeed, military technological innovation must be inherent to capitalist society. If the capitalist economic system requires political fragmentation, then for the reasons given above, it needs technological innovation for both civil and military reasons.

Because military priorities are almost inevitably at the frontiers of technology, we conclude that the most significant main general consequence of this spillover seems to be the 'early' or 'premature' introduction of certain industries. At its most extreme, it results in the establishment of industries that might otherwise never have matured, in the process foreclosing the prospects of alternative industries that might have been expected to flourish in an economic environment determined by more commercial considerations. This poses one obvious question: how important is this military process in fostering the general technological dynamism of capitalist societies? The recent US initiative on strategic defence (SDI), for example, can easily be seen more as an industrial policy than as a defence programme. Is the existence of military priorities crucial to sustaining high levels of R&D generally, or can such allocations be politically supported in other ways? A possible research approach here is the comparison of the Japanese (and maybe West German) economy with that of France, Britain or the United States. How are decisions about areas for industrial development made in an economy relatively free from the influence of military R&D priorities? On the strategic side, one might ask whether the linkage between military R&D on the one hand and stimulation of the civil economy through technological innovation on the other has negative consequences for international security. If a programme such as SDI gains political support because of its industrial policy implications, then we are maybe locked into a situation where a major element of the arms race arises from the technological needs of the civil economy.

1. Introduction

The objective of this paper is to identify the process by which military research and development (R&D) priorities affect the evolution of major sectors of the civil economy in capitalist states. Military priorities channel a significant proportion of the resources that capitalist societies devote to R&D: for the United States in the period 1982-4, military R&D amounted to 28.9% of gross domestic expenditure on R&D.(SIPRI, 1986, p. 303, Thee, 1988, pp. 7-9). The nature of military priorities favours some areas of technological development over others, and when these favoured areas are opened up for military purposes, it is often possible to build a major civil industry on the resultant technology. Examples of this process include nuclear power, civil aviation, space satellites and computers. Some, though by no means all, of the commanding heights of civil economies are thus powerfully shaped by the opportunities created by specifically military R&D.

This paper is an attempt to sketch the broadest dimension of 'spin-off' from military R&D to the civil sector, namely the distortion of investment choices that arises from military underwriting of certain kinds of technological development. The purpose of the paper is to highlight an inadequately recognised historical phenomenon, and to raise some possible questions for research, and maybe policy. We start by looking at the general relationship between military and civil technology, at the different motives that drive innovation in the two sectors, and at some deep theoretical links between these motives in capitalist societies. Section 4 surveys the history of this relationship since the early 19th century. The argument is that the century from 1845 to 1945 can be seen as a period during which states adapted to the military consequences of the apparently permanent process of rapid technological advance. Since 1945, that adaptation has become a permanent, and deeply structured, feature of state behaviour. Section 5 examines the consequences of that adaptation for four major civil industries since 1945: nuclear power, space satellites, civil aviation, and computers. Given the broad scope of this paper, and the difficulties of researching such an elusive theme, readers will need to be tolerant of counterfactual historical reasoning and the absence of systematic quantitative proofs.

2. The concept of 'spin-off'

This process is not just about individual items of civil spin-off, like non-stick frying pans, but about effects ranging all the way up to the foundation of some major sectors of the civil economy. The idea of spin-off is usually deployed in the narrow sense of transferring technology between one sector of the economy and another. But closer scrutiny is required to bring out the full range of interaction between military R&D and its civilian applications. One important general issue in this context is the distinction between invention and innovation, and the possible lags involved in the application of the former to further the latter. Innovation is possibly quite as important as new invention in creating opportunities for the transfer of technology because it highlights the fuller implications of particular inventions and underwrites, in the process, the development costs of specific paths of progress. This was undoubtedly true in the computer industry's long process of gestation from invention in the late 1940s to mass civilian application beginning in the late 1960s. This issue is of relevance in responding to the argument that some key inventions which are considered the outcome of military R&D, in fact occurred in the civilian sector. The crucial point is that the underwriting of the expensive innovation and development in the areas discussed by Thee was supported by defence funding. (Thee. op cit. p. 25).

Furthermore, ideas generated in the process of advancing specifically military R&D, especially when it involves basic research, come to constitute part of the general fund of understanding, which a recent report describes as 'tacit knowledge'. One scholar, though sceptical of both the reality and benefits of 'spin-offs' from military R&D, nevertheless asserts that modern R&D itself is a military phenomenon. Indeed he traces the origins of modern R&D specifically to the Manhattan project (Thee, op. cit p. 5). Such knowledge is about how to do things rather than about concrete inventions. In addition, 'negative' spin-off in terms of identifying blind-alleys is also important because much scientific endeavour involves testing alternative lines of enquiry. The avoidance of pitfalls is as useful as pointers towards promising lines of enquiry, *despite the prima facia evidence of detrimental consequences associated with such 'mistakes', highlighted by some observers (Gleditsch, et. al. 1986, p. 17). Much of this more subtle spin-off from military R&D to the civil sector is intangible but nevertheless valuable.

A related issue concerns the importance of time-scales, a criterion which is not fully recognised in some of the current analyses of military R&D and the phenomenon of spin-off. Recently a number of scholars (as diverse as Mary Kaldor and Nathan Rosenberg) have argued that the high specificity of much of modern military R&D has reduced the prospects for spin-off. But some of the current instances of 'absent' spin-off could still appear in the future. It is therefore quite critical to enumerate criteria that provide some indication of the time-scales at issue, either in considering spin-off as a general phenomenon, or in investigating the consequences of any particular military development.

Thus the absence of evidence of civilian 'spin-off' from a major advance in military R&D, for example, does not imply that it is unlikely to occur in the future. Indeed it may be rather difficult to identify criteria for assessing the exact future pattern of spin-off because past experience may fail to provide adequate guidelines. Much depends on the particular character of the military R&D in question and the market forces that condition the attitudes of civilian firms towards acquiring and innovating from it. Intense competition between oligopolies would elicit a different response towards the product of military R&D, and over a different time-period, than in the case of firms in a less oligopolistic industry facing greater financial constraints.

The problem of evaluating the impact of military R&D on the rest of the economy also presents formidable problems of conceptualisation and measurement. As Rosenberg argues, it is possible to cost R&D inputs at a certain level because the R&D in question is expressed in money terms. However, the output side is much more problematic because of the nature of the spin-off: the output of R&D is diffuse and elusive. Even where the links are observable, the exact meaning of the impact of military R&D cannot be expressed in comparable money terms to estimate its importance in relation to the 'input'.

A further complexity in measurement arises because of intra-industry backward and forward linkages. Buoyant demand originating in military requirements (and military R&D) in one sector can be decisive in generating innovation elsewhere. Technical innovation in high quality speciality steel might be sustained because military R&D created a higher volume of demand for the product, which in turn made certain innovations in its production attractive to the individual firm. Such linkages are diverse, important, and also difficult to measure.

The argument of various researchers that spin-off between military R&D and the civilian economy is of diminished significance can be misunderstood in one respect. They do not argue that military expenditure and accompanying R&D is without significance. On the contrary, explicit in their analysis is the argument that military R&D is consequential because it is detrimental to the civilian economy, at least in terms of choices foregone. These researchers have in mind that military expenditure has a higher opportunity cost because spin-offs from it are fewer than for purely civil R&D. Thus the idea that military R&D is important in shaping the civilian economy is, in principle, perfectly consistent with the conclusion that it is also detrimental in terms of maximising some desirable values, such as economic growth, equity, etc. (Thee, 1988 and Kaldor 1981). This perspective often begs the question of whether resources not spent on military R&D projects would in fact have been spent on civil ones. From this perspective, the possibly lower spin-off from military R&D has to be weighed against the political effectiveness of military priorities in getting resources allocated to R&D per se, as opposed to other forms of investment or consumption Blunden and Green, 1989 pp.178-79).

A more general question arising from the issue of interdependence between sectors of the economy and the difficulties of measuring the output of military R&D inputs is the timing of the third industrial revolution. This revolution, underpinned by computers (in which the military input of R&D was very large), telecommunications and nuclear energy, has been substantially fuelled by military R&D and related endeavours. The exact path and speed with which it occurred under the compelling impact of military R&D is more significant than mundane questions of definition and measurement alone. Thus one may concur with various researchers who conclude that the notion of spin-off from military R&D can only be properly evaluated if it is interpreted as covering a range of consequences that is quite varied, and wide-ranging in both time and economic scale.

As we will show, the priorities that shape military R&D have nothing to do with commercial logic. The technological opportunities made available by military R&D can nonetheless greatly alter commercial logic in many sectors of the economy. The sunk costs of military R&D can advance the introduction of an industry by many years or even decades. It seems highly unlikely, for example, that either mass air transport or space satellites would have developed anything like as early as they did if it was not for the fact that military R&D laid massive 'premature' foundations for them. The commercial nuclear power industry might never have developed at all in its current form without the military impetus.

The existence of a large, militarily directed R&D thus introduces a substantial distortion into what would otherwise be the 'natural' development of a civil economy shaped by a more purely commercial logic. The notion of 'natural' development includes state intervention to promote desired areas of the civil economy. What we are trying to draw attention to here is the distinction between military R&D priorities and commercial ones, regardless of whether the latter come from the state or from the private sector. The cultivation of civil industries on technological foundations developed for military purposes can of course be commercially sensible once the sunk costs for much of the necessary R&D have already been paid. Spin-off on this grand scale provides an important mechanism by which capitalist societies can support and defray the costs of maintaining their military strength. But the rise of these industries may well cause the premature decline of established sectors that would otherwise have remained commercially viable for much longer. Passenger rail and shipping, for example, were practically wiped out in some countries by the rise of civil aviation.

Similarly, the rise of premature military industries may suppress the development of alternative technologies that would otherwise make commercial sense. There can be little doubt that the promotion of civil nuclear power on the back of military R&D, despite the shaky experience of the civil nuclear reactor industry, has suppressed the development of alternative technologies for generating electrical energy. It is of course difficult to pose the counterfactual of what would have occurred in the absence of some specific historic military R&D decision such as nuclear fission, or computer applications. But there is a widespread conviction that most of the civilian outcomes would have happened anyway. In our view some qualification to this assumption is justified. For example, civilian nuclear energy only made sense because of the development of nuclear weapons technology, and it is by no means certain that alternative energy forms, including further development of existing forms, would not have become dominant if R&D resources had not been diverted by the nuclear opportunity. According to some researchers alternative energy forms, especially solar energy in warmer climates, are quite feasible. If, in the absence of nuclear weapons programmes, other energy forms had received R&D

priority, the significance for the economy and the polity would have been profound.

It seems worth drawing attention to this phenomenon not only because it raises interesting questions about how new technologies shape the evolution of the civil economy, but also because it points to a systematic distortion in resource allocation which has profound effects on some of the economic and social choices that modern capitalist/industrial societies have to face.

In order to bring into focus the multiplicity of channels through which military R&D potentially affects the civilian economy it is useful to step back to the most general level of analysis, the international political system. In this context the relationship between sovereign nation-state actors, the principal constituents of the international political system, is conceived as a process of competitive reciprocal interaction (action-reaction), occurring across a wide range of issue-areas. The competitive relations of states include both technological goals in general and military R&D in particular. The state is the key player in the arena of technology policy, including specifically military R&D, which is part of the broader military competition between sovereign actors. The sources of this competition are essentially politico-military in character. The design of technology policy to ensure a measure of national self-sufficiency so as to reduce exposure to uncertainty emanating from the outside world, really acquires full meaning because inter-state relations are always potentially conflictual.

In taking recourse to the highest systemic level of analysis as the referent, our purpose is to draw attention to the political nature of state technology policy and not merely military R&D. If state technology policy is designed to reduce market imperfections, and thus narrow the divergence between private and social costs, it would be necessary to demonstrate empirically first, that the policy intervention was indeed motivated by such concerns, rather than by the fear that the particular technological advance was worth acquiring to prevent advantage accruing to rivals, and second, that private agents could either not ensure the availability of the technology locally, or could not do so within a reasonable time span. It is appropriate to stress that this issue is an empirical one, in that state technology policy could, in principle, be motivated by the desire to reduce market imperfections. However, we argue to the contrary state that technology policy is in fact impelled by the goal of maintaining and/or securing national competitive advantage. Even in a seemingly innocuous sector like motor vehicle technology, economic policies in most European countries were motivated not only by concern for competitiveness in a major sector, but also by awareness of its direct military significance (Wells Jr. in Vernon, 1974, pp. 227-254). Thus the politico-military impulse, both generally and specifically (ie, of direct military relevance), is likely to recur regularly in state technology policy, with attendant consequences for the private economy.

A related question in the context of relationships within the international economic system is the impact of military R&D through its transmission across international borders. Normally, comparisons are made between some measure of economic performance and its correlation with the magnitude of military R&D in a particular country. In a remarkable number of instances this correlation is a negative one (CSS, 1986, p. 42 for example).

It could be argued, however, that in practice one country might underwrite the cost of the original inventive R&D activity but its successful large scale civilian application could occur elsewhere. Thus the fact that Japan does not engage in major military R&D does not preclude it from benefitting from fundamental military R&D advances which occur in other countries. The fact that a successful economy is not engaging in significant military R&D is not a persuasive argument in favour of the possible independence between military R&D and the civilian economy; indeed Japan did have a balance of payments deficit in patents for most of the postwar period despite a competitive advantage in manufactured exports. US weakness in manufacturing need not necessarily originate in the allocation of comparatively large resources to military R&D. To put it another way, a sharp diminution in US military R&D could fail to solve the problem of such competitive weakness (the origin of which could be social in the sense employed by Mancur Olson (1982) for example). Any such slowing down could eventually (once the existing stock of imported knowledge begins to date) slow down innovatory application in Japanese industry, which is ultimately dependent on fundamental research originating in the military sector of the US economy.

3. The Relationship Between Military and Civil Technology

In common usage, the term 'military technology' often suggests that military technology is quite distinct from that in the civil sector. Usage of this kind is reinforced by terms such as 'arms racing' and 'the military-industrial complex' both of which emphasize phenomena that stem from the peculiar characteristics of military technology. In some respects, the separation of military from civil technology is perfectly justified. Heavy artillery; aircraft carriers; precision-guided, armour piercing anti-tank missiles; nuclear warheads; anti-submarine noise detecting and discriminating systems; terrain contour guidance systems for cruise missiles; automated gatling guns for point defence against missiles; and many other devices, have few, if any, civil applications. Similarly, many military applications of technologies also found in the civil sector, such as jet engines, communication equipment, microprocessors, and even lorries, require modifications to specification well beyond those in the civil sector. Jet fighter engines need far higher power-to-weight ratios than those for commercial aircraft. Military microprocessors and communication equipment may need to be built so as to perform reliably in a much wider range and variety of environments, some very harsh, than would be expected of similar devices in the civil sector.

But the partial validity of the distinction between military and civil technology too often hides the underlying fact that both are part of the same broad pattern of knowledge and industrial capability. Although military technology may pursue some routes peculiar to itself, and may in some sectors serve as the leading edge for developing new capabilities, it is nonetheless closely tied to the general character of civil technology in terms of knowledge and industrial capacity. In crude terms, an economy that can build jet bombers, intercontinental ballistic missiles, tanks and computerised guidance systems, can also build jet airliners, satellite launchers, automobiles and personal computers -- and vice versa.

An economy that cannot build the one is most unlikely to be able to build the other, as illustrated by various abortive attempts to found arms industries in Third World countries lacking an appropriate level of civil industrial development. (Brzoska and Ohlson, 1986, pp. 281-2) The military potential of civil technology is illustrated not only by such events as the mobilization of the United States during the Second World War, but also by the 1983 agreement between Japan and the United States on the transfer of militarily significant technology from the largely civil, but very advanced, Japanese economy, to the quite highly militarised, but in some ways less advanced, American one.

The point here is that both military and civil technology stem from a common stock of scientific and engineering knowledge. Although the machine guns that began to be manufactured in the 1880s represented a military application of contemporary skills in metallurgy, precision engineering, and design, much the same knowledge was simultaneously producing typewriters and sewing machines in the civil sector. Any economy that could produce the one possessed nearly all of the capabilities necessary to produce the other. From this point of view, it becomes clear that the gap between civil and military technology is always quite limited in size when compared with the overall base of knowledge and industrial capability from which both spring. In some areas, such as transport aircraft and helicopters, technologies in the two sectors may just be different applications of virtually the same knowledge and skills. In others, such as the jet fighter engines mentioned above, the military sector will develop technologies that are either unique (in the sense of not wanted for civil application) or advanced (in the sense of not yet cost-effective for civil application). Even in this latter case, however, developments in the military sector cannot far outrun the common stock of knowledge and industrial skill. Although such developments may well push forward the frontiers of the technologically possible, their position on those frontiers is constrained by the overall shape and extent of existing knowledge.

The underlying closeness of civil and military technology has quite profound consequences for how one views important phenomena ranging from arms racing (Buzan, 1987) to surplus productive capacity in many industrial sectors of world trade.(Sen, 1984) In the present context, this inherent closeness underpins, and perhaps even amplifies, an important confluence of interest within capitalist societies in technological innovation for both civil and military purposes. The civil imperative for technological innovation under capitalism links directly to the profit motive. By either increasing efficiency in existing economic activities, or opening up new markets altogether by stimulating new activities, technological innovation provides one of the most attractive sources of profit in a capitalist economy. Technological advance offers capitalists a permanent escape route from markets that have become saturated because the proliferation of the relevant knowledge and industrial skill has driven profits down to marginal levels. It also offers the possibility of domestic political stability, inasmuch as general economic growth based on continuous technological innovation avoids the confrontational class politics that almost inevitably attend distributional struggles in a stagnant economy.

The military imperative for technological innovation is quite different in origins from the civil one, though obviously complementary to it. In the anarchic society of sovereign states, each government is responsible for protecting its state against the possibility of military attack by others. Simple prudence requires states to maintain military forces that are in some sense proportional to the military threats that others can bring to bear on them. Such threats are a combination of the military capabilities of other states with their aggressiveness -- the likelihood that they will use their capabilities offensively. Military capabilities stem in part from existing, and likely future, levels of technology, especially so in relations amongst industrialised states. This fact means that states must be sensitive to the military implications of technological innovation as part of their military security policy. To fall behind risks becoming vulnerable to grave defeats like those inflicted by the Europeans and the Japanese on China during the nineteenth century.

Military rivalries amongst industrialised states thus tend systematically to promote the development of military technology. Falling too far behind the prevailing technological standard seriously undermines one's relative military capability. Occupying the leading edge of the prevailing standard conversely offers a security premium. These dynamics can be illustrated by cases as diverse as the British introduction of all-big-gun 'Dreadnought' battleship in 1906, to the contemporary American effort to devalue Soviet strength in offensive missiles by developing strategic defence technologies. Where the rivalries are longstanding, with every prospect of remaining so, the action-reaction process of technological competition develops into a smoother pattern. Like the United States and the Soviet Union; both sides internalise and institutionalise the process of innovation in an attempt to anticipate what the other might do. The long lead times for complex weapons systems require a continuous process of innovation across a broad front in order to maintain one's relative position, as illustrated by the fact that the two superpowers together spend about 16% of their total military expenditure on military R&D, a sum amounting in 1985 to $64 billion, or to 8% of the world total of military expenditure.(SIPRI, 1986, pp. 299-303)

This confluence of interest in technological innovation, both military and civil, within capitalist states links to the historical association between capitalism and anarchic (ie. politically fragmented) international systems. As several writers have pointed out, capitalism only arose in Europe because of the failure of European civilization to achieve political unity on the imperial model of China. (Wallerstein, 1974; McNeill, 1982; Chase-Dunn, 1981) Only the relative freedom from central political control created by a multi-state anarchy allowed market behaviour to become a dominant social and economic force. To the extent that this quite widespread historical interpretation is valid, then military and civil technological innovation in capitalist societies go hand in hand: indeed, military technological innovation must be inherent to capitalist society. If the capitalist economic system requires political fragmentation, then for the reasons given above, it needs technological innovation for both civil and military reasons. Within the fragmented political structure of Europe, competitive market behaviour stimulated civil technological innovation at the same time as state power rivalries stimulated military technological innovation. This synergistic combination rapidly made the European states into the centre of a world-spanning series of empires, which laid the foundation for the present global dominance of the capitalist system. Since the historical success of capitalism has been based largely on its generation of technological innovation, and since that innovation has always been as much stimulated by military as by civil imperatives, it should come as no surprise that strong relationships exist in such societies between military R&D priorities and the shape of major sectors in the civil economy.

4. The History of the Civil-Military Technological Relationship

Before turning to look at our four cases, it is useful first to recount briefly the history of the civil-military technological relationship. The period of greatest interest in this context begins around 1840, when the pace of innovation in the industrial revolution really began to take off. Before that point, and for several decades after it, military technology did not have the relatively clear 'leading edge' position with which we associate it today. Even in the 18th century, military demand often played a key role in stimulating basic industries like iron and steel, and in creating moves towards standardised mass production techniques.(McNeill, 1982, pp. 170-2, 177, 210-11) But in most sectors, it was the civil market, whether promoted by the state or by the private sector, that led the process of technological innovation. Steam power, and its application to factories, railways, and shipping, all developed in the civil sector well before there was any military interest in them. Indeed, it is well known that the Royal Navy resisted the introduction of steam and iron, clinging to wood and sail well into the 1850s, long past the point at which commercial shipping had begun to develop and use steam driven metal vessels, such as Brunel's Great Britain of 1845. Even in the much later case of the internal combustion engine, and its application to aircraft and motor vehicles, the military took little interest until forced to do so by the pressures of the First World War. In the two decades before the First World War the early development of both aircraft and automobiles was entirely in the civil sector, though navies did eventually get around to developing submarines using the new technologies of internal combustion and electric engines.

The pattern of a strongly focused, and in some senses dominant, insertion of military priorities into R&D did not emerge until quite late in the 19th century. Both McNeill and Pearton have traced in detail the history of the process by which the governments of industrialized states became ever more entangled in the promotion of military R&D. (McNeill, 1982; Pearton, 1982) In the early stages of industrialisation, the arms industry was market based, but as technologies rapidly became more complex and expensive, increasingly close connections developed between a shrinking number of large companies, and the governments who became the principal purchasers of their products. This process began with naval procurement, where the shift from wood and sail to steel and steam beginning in the 1850s unleashed a long period of rapid technological change, escalating costs, and unstable international rivalries. Given the crucial importance of naval power to British security, the government had little choice about keeping its naval technology at least level with that of military competitors like France. The scale of procurements required, and the intensity and cost of the R&D necessary to maintain naval dominance, fairly quickly transformed the market-based arms industries into something more like a command mode between the 1860s and the 1880s. (McNeill, 1982, 240-1, 278-85, 334)

This shift towards increasing state involvement with innovation and production of military technology stemmed naturally from the impact of the much intensified pace of technological innovation generally from the 1840s onwards. The steady flow of new capabilities created permanent pressure on what had traditionally been much more stable calculations of military balance. New weapons were much more costly than older ones had been. If the state wanted to keep its armed forces adequately adapted to the broad pace of technological advance, then considerable management of research and development choices became necessary. The commercial sector alone could not be expected to sustain the costs and risks of such large, high-technology projects. In addition, once the state began to adapt itself to an environment of permanent, rapid, and often dramatic technological change, its institutions naturally wanted more say in how the new technological opportunities would be applied to the state's military requirements. Military power came increasingly to depend not only on the flourishing of the industrial sector as a whole, but also on the cultivation and maintenance of specialised companies. These companies had to be capable not only of keeping up an appropriate standard of military R&D, but also of keeping available sufficient production capacity to meet expanded state demands for military goods in emergencies.

This natural merger of state and military-industrial interests was accelerated by the tremendous increase in military demand created by the two World Wars. As Pearton traces, these surges of wartime demand did much to institutionalise the process of state-directed military innovation. That institutionalisation itself took place against a background of continued scientific and technological advance which required government involvement not only at the level of technological application to military requirements, but increasingly in the basic processes of innovation itself. New knowledge, such as in electronics, opened up unprecedented capabilities of profound significance to the deployment of military power. The possession of telecommunications and radar, for example, utterly transformed the environment of military operations. As a consequence, the military priorities of the state necessarily reflected the increasing importance of technological innovation in the design of weapons systems. To preserve its relative military position, the state had to interest itself in the basic sources of that innovation. Pearton sees this process as culminating in the intrusion of the state not only into industry, but also into work at the frontiers of science. He argues that the Manhattan project of the Second World War brought government into the last remaining civil domain -- pure science -- and completed the erosion of the civil-military boundary by bringing government, industry, and science all together throughout the entire national structure.(Pearton, 1982, 239-44).

By 1945, then, the institutionalisation of state interest in technological innovation for military purposes was essentially complete. In this sense, the century from the mid-1840s to the mid-1940s can be seen as a period during which states adapted to the military consequences of the apparently permanent process of rapid technological advance that first became prominent during the middle decades of the 19th century. From 1945 onwards, it was normal behaviour for industrialised states not only to maintain a substantial capability for military production, but also to dedicate a significant proportion of their R&D resources towards technological objectives set by military priorities.

In reflecting on this adaptation, and its consequences for the civil sector, it is worth thinking for a moment about just how military R&D priorities differ from those in the civil sector. In the civil sector, broadly speaking, new technology is useful in three ways: lowering the costs of producing already existing goods, allowing superior goods to be produced at a cost that the market will bear, or providing previously unavailable goods that open up new markets. Standards of profit and relative cost-efficiency set the framework within which technological innovations are sought and developed, though governments also intervene here with some socially determined demands for goods such as railways and pollution control devices.

In the military sector, technological innovation is sought in order to enhance performance capabilities in relation to existing missions, such as the accurate delivery of destructive power over long distances, or to make new missions possible, like evading naval blockades with submarines, or finding ways of shooting down previously unstoppable missiles and their payloads. The desire to achieve a specified military capability is normally driven by the need to keep pace with, or stay ahead of, the performance of military rivals. Although costs pose an overall constraint on the pace and extent of what can be sought for, this constraint is normally much less severe than in the civil sector, where alternative sources of profit quickly limit risky, long-term, and/or cost-inefficient technological projects. In the civil sector, for example, aircraft engines need to be quiet, reliable, fuel-efficient, and to have low ratios of maintenance to flight hours. Engines for jet fighters, by contrast, demand much more emphasis on performance in terms of power-to weight ratios. Although fuel-efficiency and reliability also figure as objectives, if the goal is a top-class air-superiority fighter like the F-15, then these will come second to the maximization of performance. Such maximisation will inevitably stretch the limits of the technology. It will require performance objectives that may never be of interest to the civil sector, and will entail maintenance ratios and running costs that would certainly be unacceptable to civil operators. Since the performance logic that shapes the demand for military technology derives from the capabilities of rival states, and the threats that they pose, there is continuous pressure for innovations in military technology to push at the boundaries of the technologically possible. Those boundaries seem, in theory, to be infinitely extendable. As a consequence, military rivalries between industrial states are continuously subject to the simultaneous excitement of possibly stealing a major lead over one's rival, and angst, that one's rival may do the same in reverse. This is a permanent situation until either the system of sovereign states is transcended by world government, or the absolute limits of humankind's technological ingenuity are reached. Neither seems imminent.

The kinds of technological capability needed to fulfil military requirements may or may not run parallel with actual or potential civil applications. The development of military aircraft from the First World War onwards, for example, was driven by the desire to improve performance in the three missions developed during 1914-18: long-range bombardment, reconnaissance, and air defence. These missions required sustained improvement across the board in almost every aspect of aircraft performance: speed, altitude, range, carrying capacity, reliability, and navigational accuracy in all weathers. Although pushed by military competition, this development of aircraft technology fairly quickly reached the point at which civil uses could be served, ranging from sport and scientific exploration to commercial transport of mail and passengers. The enormous effort put into the development of heavy bombers during the Second World War laid both the technological and production foundations for the rise of the long-range civil aviation industry during the postwar period. The kind of aircraft that were needed to deliver large bomb loads over distant enemy territories were in many ways similar to those required for trans- and inter-continental passenger and light freight services.

In the postwar period, however military developments in aircraft performance have in many respects outpaced the requirements of the civil sector. Large jet bombers like the B-52, and the more recent B-1B and 'Stealth', represent design requirements that have no likely parallel in the civil sector. The B-52's extreme range requirement makes it little more than a flying fuel tank, and there is no present or likely future civil analogue for the quick takeoff and very low-altitude flying capabilities of the B-1B. At best, some of the technical lessons learned for the B1-B might help the development of a supersonic passenger airliner, though even with the military R&D foundation the commercial demand for such aircraft is questionable on both cost and environmental grounds. It is hard to foresee any civil applications of the 'Stealth' technology. High performance jet fighters and reconnaissance planes like the F-15 and the SR-71 similarly represent an area of military development well beyond the likely requirements of the civil sector.

Where military and civil functions are more similar, as in transportation requirements, substantial technological complementaries can still occur. Good examples here are the use of several aircraft -- Boeing 707, DC-10, VC-10 -- as both aerial tankers for the military, and passenger airliners and freighters in the civil sector. Many helicopters have dual military and civil roles. The joint project between Boeing and Bell to develop 'tiltrotor' aircraft is operating on the assumption that military funded R&D, and substantial orders from several branches of the US armed forces, will underwrite most of the development costs for civil versions of this versatile S/VTOL aircraft. (interviews at Bell, Fort Worth, August 1987) Likewise, the development of a new generation of airships by companies like Airship Industries is banking on an initial military input of orders and development funds in order to underwrite longer-term developments for civil markets. (Economist, 13/6/87, p. 72) Because of their high development costs, neither of these latter projects would be likely to reach the civil market unless military demand was sufficient to pay for most of the initial development costs.

5. Military R&D and Distortions in the Civil Economy Since 1945

The justification for focusing on the period since the Second World War hinges on the argument made above that 1945 was, in many basic respects, the culmination of a century-long adaptation by industrial states to the military consequences of permanent technological innovation. As a result of both two major wars and a century of technology-based military rivalry, by 1945 the process of state-promoted technological innovation for military purposes was deeply and permanently institutionalised in all the major powers. Given that technology-based military rivalry has continued to be a strong feature of international relations since 1945 -- and shows every sign of continuing to be so for the foreseeable future -- it can be argued that we are looking at a relatively stable structure in the economies of advanced capitalist states. To some extent Japan, and less so West Germany, serve as controls for observing this process. Because of their status as losers in the Second World War, neither country has a military industry of the size and shape that would normally be expected for the power of their industrial economies.

In dealing with this period as representing a new norm, one is faced with the difficulty of separating the intense and particular effects of the Second World War from the more stable and ongoing underlying effects of military rivalry in general. The extreme pressures of total war not only accelerated some areas of innovation that were already well established, most notably in the development of aircraft, but also catapulted other areas -- nuclear physics, rocketry, computers -- from the obscurity of laboratories into the front-lines of military industry. Because of the War, not only was the pace and direction of technological innovation greatly affected, but also large production facilities were created. Both Britain and the United States had built up massive aircraft production capacity,(Sampson, 1977, ch. 5) and the United States was heir to all of the expensive facilities constructed for the Manhattan project. Some of the impact of military R&D on the civil economy since 1945 thus has to be seen as reflecting the momentum of the war. In all cases, however, that momentum was fed and sustained by the ongoing process of 'normal' military rivalry that reasserted itself immediately after the war.

We have identified four major civil industries whose development in the postwar period has been fundamentally influenced by the dynamics of military R&D priorities. These can be sketched as follows.

5.1. Nuclear Power

The civil nuclear power industry can be considered one of the most striking cases of how military R&D priorities can distort the civil economy. Without the extreme stimulus of the war, it seems highly unlikely that any state would have paid the enormous costs involved in attempting to harness atomic energy at a time when the knowledge base was uncertain, and the prospect of failure considerable. In time, the military lure of atomic power might well have fed its way into military R&D, but not in the precipitate and extremely early fashion that in fact occurred. Although the startup costs of the nuclear industry were paid by the wartime Manhattan project,(Brodie, 1973, pp. 254-7) military demand for sustained development and production in the nuclear field continued into the postwar period, riding on the back of the Cold War that quickly ensued between the United States and the Soviet Union. The military needed large quantities of fissile material for two reasons: firstly, to build-up, improve, and test an arsenal of nuclear explosives; and second, to fuel reactors for use as propulsion units in submarines. The scale of this demand was sufficient to require substantial developments in the mining and processing of uranium; in the design and development of reactors to manufacture plutonium; in the construction of large-scale enrichment facilities for extracting the rare fissile isotope U235 (0.7%) from the bulk of non-fissile U238; and in the construction of reprocessing plants to handle spent fuel from reactors. Military nuclear projects, in other words, created much of the training, knowledge, infrastructure, and production plant necessary for a civil nuclear industry.

Nuclear explosions had very limited prospects in civil use despite some early, and now largely defunct, enthusiasms for massive civil engineering applications such as canal digging and mining. But nuclear reactors offered two civil options: electricity generating plants, and propulsion units for shipping. In the American case, light-water reactors developed for submarines were eventually adapted for use as electricity generators, while in Britain, reactors developed for plutonium production filled this role. Although reactors found homes in an ever wider variety of naval vessels, where their endurance without refuelling was a major asset, neither cost nor environmental considerations favoured their use in commercial shipping. Except for some icebreakers, there has been no commercial spin-off in this application despite efforts by both the American and Japanese governments to promote it.

The civil nuclear power industry has had a troubled history despite the advantages of its very substantial piggyback on the military sector. Until the 1970s, cheap oil limited the attractions of atomic plants for electricity generation. The oil crisis gave the industry a decade-long boom on the basis of improved cost comparisons and security of fuel supply considerations, but that has now faded. Comparative fuel costs have swung back in favour of hydrocarbons, and the nuclear industry has experienced serious escalations in its capital costs, difficulties of efficient operation, and environmental opposition. Ironically, one of the principal attractions that civil nuclear power still possesses is that it offers non-nuclear weapon states a respectable way of acquiring a short option on a military nuclear capability. Possession of reactors, enrichment and/or reprocessing facilities gives a state command of all the basic technologies needed to produce fissile material for military purposes should the government find itself in need of that capability. This attraction has been a major feature of interest in civil nuclear industry in countries such as India, Pakistan, Brazil, Argentina, Taiwan, South Korea, South Africa and in a more subtle way, probably also in West Germany and Japan. (Buzan, 1987, ch. 4)

Although the civil nuclear power industry has not been an enormous commercial success except in a few places such as France, it has nonetheless had a substantial impact on the civil energy sector overall. Nuclear power has absorbed most of the research effort into alternatives to fossil fuels, and in so doing has changed the orientation and the technological content of the electricity generating industry. Even with the huge boost it received from military R&D civil nuclear power has failed to carve a dominant position in the industry. Without that boost, it is possible to imagine that it would not yet have developed at all.

5.2. Space Satellites

As with atomic power, it is easy to imagine that the contemporary space industry based on communications and earth surveillance satellites would not yet exist at all if its development costs had not been hugely underwritten by military R&D. The Second World War promoted rocket technology most strongly in Germany, and this expertise was commandeered by the United States and the Soviet Union as part of the spoils of their victory. The attractions of marrying atomic weapons to rocket delivery systems were seen quite early, and by the mid-1950s, competition between the superpowers in the development of military rockets was firmly established. This rivalry quickly led to the development of successive generations of rockets powerful enough and reliable enough to be used for putting payloads into orbit. The military also took the lead in developing satellite technologies in order both to meet its own demands for global communications capabilities, and to provide means by which the military activities of the opposition could be kept under close and continuous observation.

This military foundation initially primed the development of quite extensive state-supported space science, which further developed technology alongside, and in some ways complementary to, the ongoing military programmes. Commercial activity initially took place as a sideshow within state-sponsored military-scientific institutions such as NASA. Lately, however, the trend is towards organizations that are more commercially distinct, such as the Arianespace consortium in Europe.

The future of this nascent industry is still not very clear, and neither is the extent and shape of distortion created by it in the rest of the economy. The commercial demand for communication, broadcasting and observation satellites seems likely to remain strong for the foreseeable future, and will continue to run in close parallel with many of the ongoing military and scientific uses of space. Any further expansion of activities into areas such as manufacturing, solar energy, tourism, and low-gravity medicine will depend on the willingness of states to develop space infrastructure and technology well beyond their present levels. In other words, the takeoff point for a full-spectrum space industry has not yet been reached despite the large military inputs already made. There is, however, every evidence that military priorities will continue to encourage, and therefore to underwrite, the sorts of technology necessary for the eventual development of space industries. Military control of the 'high frontier' for purposes ranging from communication and surveillance, through navigation, to strategic defence and bombardment, looks irresistibly tempting so long as international relations remain infused with great power rivalry. So far, the existing civil uses of space have probably had little impact on the civil economy overall. They may have caused some reduction in the use of alternative communication and broadcasting technologies such as cable, but it seems unlikely that the impact here has been on any scale comparable to that of nuclear power in the energy sector. Without the military lead, it seems quite certain that any commercial, or even scientific, development of space, would have come many decades later than has in fact been the case. In time, the military opening of space could have profound repercussions for the civil economy that will come decades earlier than would have been the case in the absence of the military lead.

5.3. Civil Aviation

The linkage between civil aviation and military R&D differs substantially from that of either nuclear power or space satellites. Unlike them, civil aviation did not spring so clearly from developments made during and after the Second World War. Instead, it reflects a longer-running process also taking in the First World War and the two decades of military rivalry during the interwar years. As discussed above, the striking thing about aircraft technology was the extent to which the first four decades of militarily promoted development were so fundamentally complementary to the needs of the civil sector. Improvements in range, carrying capacity, reliability, navigational accuracy, all-weather operating capability, fuel-efficiency, and, up to a point, speed, all served to open up opportunities in the commercial sector. Developments during the Second World War accelerated trends already apparent earlier, though one wonders whether jet engine technology would have seen the light of day anything like as early as it did if it were not for the imperatives of wartime priorities. Perhaps the main contribution of the Second World War to existing trends was the development of heavy, long-range aircraft, and the legacy of a massive aircraft construction industry.

In the period after the war, the onset of military rivalry between the superpowers ensured that military requirements for aircraft would remain substantial, and that military rivalry would drive technological innovation. Despite the shift to rockets for delivering nuclear weapons demand for bombers has continued as a means of diversifying the nuclear deterrent (and also of preserving the identity of the air force). Many of the military aircraft built since the 1960s have pursued technologies beyond those useful to the civil sector. There remains nonetheless a useful traffic in technological complementarity in both directions between the civil and military sectors of the aircraft industry, a fact attested by companies like Boeing and British Aerospace that regularly work in both. In selected areas, like helicopters and some V/STOL aircraft, the complementarity remains high.

Given that the development of aircraft before 1914 occurred largely in the civil sector, one cannot argue that, like nuclear power and space satellites, civil aviation would not have developed without the impetus of military R&D priorities. What can be argued, however, is that once military interests began to push and shape R&D priorities in aviation, the development of the technological capabilities necessary for a widespread civil aviation industry occurred substantially earlier than would otherwise have been the case. The development costs for the kind of long-range, heavy aircraft that have become the workhorses of civil aviation would have appeared quite daunting if the only reward was the prospect of a highly uncertain and distant market in mass transportation. As Sampson notes, despite the boom in civil aviation starting during the 1950s, 'the commercial aircraft still could not be [economically] viable on their own, and the military programmes were carrying the commercial on their shoulders.' (Sampson, 1977, p. 101) The natural confluence in technology between the early stages of military requirement and the needs of the civil sector thus clearly accelerated the arrival of the mass transit civil aviation we have today.

The consequences of that acceleration for the rest of the civil economy have been large. On the positive side, have been huge downstream developments in tourism, air-freight, and the numerous manufacturing and service industries associated with them, made possible by the shrinkage in transportation times. On the negative side, other transportation industries, like passenger shipping and railways have been forced into premature decline, with consequences for their associated basic industries like steel, shipbuilding and heavy engineering. Because of specifically military priorities in both R&D and production, civil aviation developed prematurely, imposing a major distortion on what would otherwise have been the development pattern of the civil economy.

5.4. Computers

The computer industry first emerged during WWII in the cryptographic division of the Ministry of Defence in the U.K. Specialist computers were developed for code-breaking and ballistic calculations (Hills 1984, p.91). State intervention arising from interest in potential military applications continued after WWII. Over time, the size of the civilian market outstripped the value of defence procurement, but the latter remained a paramount conditioning factor for the computer and allied industries.

Computers have diverse applications in defence, from sophisticated C^3 systems for nuclear deterrence and targeting to analysis of large volumes of data and efficient stock control. The deployment of revolutionary computing capacity in the SDI programme will also introduce a qualitative new dynamic. In computers, as in other areas of technology of interest to defence, the "modus operandi (for the US) ....is developmental, using the military not only to underwrite technological development, but also provide initial markets for the resulting products via government procurement" (Erik Arnold & Ken Guy 1986, p.35).

The significance of defence-sponsored intervention is underlined by its role at crucial junctures in the history of the industry. One turning point in the American semi-conductor industry, for example, was the decision in 1962 by NASA and the USAF to use integrated circuits (ICs) in the Apollo project and in Minuteman Inter-Continental Ballistic Missiles; the Apollo programme placed an order for 200,000 ICs. With a rejection rate of 75% in the early 1960s ICs remained commercially unviable for almost a decade and the development costs were being underwritten by the US Department of Defense. Interestingly, ICL, the British computer firm, questioned the adequacy of preferential government procurement alone in establishing a local production and design capability. According to Hills, "It wanted to cut its teeth on new applications, giving it experience which it could then use as the basis for contracts in the export market. It argued that the American industry had become established and experienced through the use of 'development contracts' from the Department of Defense" (Hills, p.159, and Blunden and Owen, p. 118).

In the 1980s "the DOD initiated a Very High Speed Integrated Circuit (VHSIC) Programme to develop significantly faster, large monolithic chips oriented to military requirements." (Arnold & Guy, p. 40). The Committee on Assessment of the VHSIC Program recognised its eventual commercial importance, particularly in assisting US industry against Japanese competition (Arnold & Guy, p. 42). The other area where the defence industry has been crucial is in the development of the supercomputer industry. In 1985 half the Cray machines were acquired by government and it also funded (in 1982) over 70% of the industry's R & D. Furthermore, overall the DOD in the US was providing 25% of the total R&D of the electronics and computer industry, excluding the endeavours of the substantially defence-inspired space programme. However, the rapid evolution of the civilian computer market has led defence analysts to lament the relative backwardness of military as compared to civilian applications. Observers argue that local branches of banks in Germany use more advanced equipment than NATO headquarters in Brussels, and the transfer of techniques ought to be from the former to the latter. The point is that civilian applications are more widespread, as reflected in the 97% share of civilian business in IBM's turnover. But the important question is the role of defence as a catalyst, affecting, at the very least, the timing of the spread of innovation to the civilian market and indeed moulding some of the specific choices. The SDI, dwarfing existing government involvement and funding, is apparently on the threshold of precipitating another major qualitative transition that will transform both costs and choices for the industry.

6. Conclusions

The principal purpose of this paper has been to identify a major impact of the military consequences of the industrial revolution on several prominent sectors of the civil economy. Moreover, we argue that this phenomenon now represents a deeply institutionalised and apparently durable process of distortion in the civil economy. We do not take a position on whether this phenomenon is good or bad. Depending on the criteria of judgment, it may be either or both. In cases such as nuclear power, the distortion can be seen as disastrous and counterproductive in many economic and social terms. In cases such as space, it may simply be seen either as wasteful, or as a valid long-term investment in the future of the species, an assessment on which there are strong differences of opinion. In cases such as civil aviation and computers, the results seem to be generally positive in economic terms, though not without negative consequences for some older industries, and perhaps arguable both ways in social terms. The point, however, is not so much to argue a normative stance. Rather, it is to highlight a systematic distortion in the allocation of resources for industrial development, which arises as a consequence of life in the international anarchy. The question is not just one of opportunity costs, in terms of military money being denied to the civil economy, but one of distortion, in terms of military priorities changing the composition of the civil economy.

Because military priorities are almost inevitably at the frontiers of technology, the main general consequence of this phenomenon seems to be the 'early' or 'premature' introduction of certain industries. At its most extreme, it results in the establishment of industries that might otherwise never have matured, in the process foreclosing the prospects of alternative industries that might have been expected to flourish in a more purely commercially determined economic environment. One obvious question arising is how important this military process is in pushing the general technological dynamism of capitalist societies? The recent American initiative on strategic defence (SDI), for example, can easily be seen more as an industrial policy than as a defence programme. Is the existence of military priorities crucial to sustaining high levels of R&D generally, or can such allocations be politically supported in other ways? A possible research approach here is the comparison of the Japanese (and maybe West German) economy with that of France, Britain or the US. How does an economy relatively free from the imperative of military R&D priorities function, especially in terms of decisions about areas for industrial development? On the strategic side, one might ask whether the linkage between military R&D on the one hand, and stimulation of the civil economy through technological innovation on the other, has negative consequences for international security. If a programme like SDI finds support because of its industrial policy implications, then we are locked into a situation where a major element of arms racing behaviour arises from the technological needs of the civil economy.

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