Science, Technology and the Armaments Industry in the UK and Europe, with special Reference to the Period 1880-1914

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Over at least the last century, the needs of the armed forces have placed a special pressure behind the application of science to manufacturing. Consequently, the scientific content of the armament product has run at a level markedly higher than that of the industrial product aimed at the civilian market. The reason for this is brutally simple. In civilian industry, a scientific advance penetrates new markets, outpaces the competition and adds percentage points to the profit line. In defence industry, scientific advance produces higher rates of fire, more precisely directed attrition, the submarine "menace", the bomber which "always gets through", Mutually Assured Destruction, and, eventually, Star Wars. Competition is centred not on market shares but on the retention, or loss, of entire infantry brigades, convoys or cities. The stakes are higher than those in civilian industry, the imperatives are more urgent, and the penalties for under-performance sharper.

The military in the modern era has displayed a special interest in the exploitation of industrial science so as to achieve tactical or strategic advantage. Also, of course, it commands special resources to assist in this process. It will invest enormous amounts to secure these advantages, and historically, the political and social values of the European nations have allowed it to do so. The military bank, spending through the public purse, has proved a massive paymaster of scientific development. Moreover, the military can afford to take the long view: it is worth waiting for large strategic advantages. Thus onerous or time-consuming scientific programmes will often be funded by the military when private interest can afford neither the time nor the money for them. Commercial interest usually presses for quicker returns.

In recent decades, these considerations have tended to produce a swing in the funding of the most complex and often most "pure" research towards the defence establishment. The movement has been away from the position where the military, through its procurement machinery and its specifications for weaponry, encouraged private industry towards a high level of scientific sensitivity, and in the direction of one where a high proportion of an economy's total research and development is funded directly by the military. This transition began in the UK and Germany in the first two decades of the twentieth century and reached a peak perhaps in the USA of the 1960s, when around 60% of all American research and development was financed by the US Department of Defence.

Some critics have argued, of course, that military expenditure has created a machine of immense, grotesque and needless intricacy, a "baroque arsenal" of self-perpetuating over-elaboration.[1] The proper riposte is to enquire what is the *alternative* source for a major proportion of pure research — research much of which will be wasted but an unpredictable fraction of which will yield huge military, and civilian, advantage — if the defence account is not to be drawn upon. Advanced societies have proved able to survive the over-elaboration, but can they sustain themselves upon radically reduced levels of pure research or find equivalent imperatives for maintaining these levels? In an era when there is much talk of the "peace dividend", it is a pressing question.

An Early Peak: Military Innovation, 1880-1914.

The focus of this paper falls upon the influences at work in some of the earlier stages of the relationship between military demand and technological progress. By definition, the military is a central and concentrated source of influence. For it to exert pressure upon a body

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[1] Mary Kaldor, *The Baroque Arsenal* [London, 1982].

as large and diffuse as an entire industrial sector [or several], it was necessary for that sector [or sectors] to have developed a particular type of institutional and technological structure. Key support industries, such as metal-making, engineering and chemicals — which remain fundamental to armament production — needed to attain a level of sophistication at which scientific input was a normal part of their method of functioning. Secondly, it was important that they should develop formal systems for organising the science — effective laboratories, teams of scientific personnel, research programmes — in order to supply the institutional connexion between investigation and manufacture. Once the civilian support industries had developed such features, specialised defence firms, drawing upon these technologies, but also responding to the refined pressures imposed by their military customers, could move into the manufacturing vanguard. But before an elite group of defence suppliers could attain this pre-eminence, an industrial matrix was needed which could receive the pressure from the military centre.

In the relatively advanced economies of Britain, Germany, France and the USA, these processes first got under way within the timespan 1860-90. This period witnessed the birth-pangs of the modern military-industrial complex. It also saw the growth of specialised defence firms which outpaced their civilian counterparts to become "best practice" exponents of industrial research and development. The possibility follows that these firms could become instructors or scientific guides to the related civilian industries. For, if the products which the armed services sought were unique to military need, the processes and practices necessary to make them, and the materials of which they were made, were capable of much wider applications. Thus, "spin-off" became a systematic feature of the high-technology economy: innovations generated under the pressure of military demand could be transferred — or "spun off" — to more general use within non-military industry.[2]

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[2] Clive Trebilcock, "Spin-Off in British Economic History: Armaments and Industry, 1760-1914", *Economic History Review,* 22, (1969) and 24, (1971); "British Armaments and European Industrialisation", *Economic History Review,* 26 (1973) and 27, (1974).

Of course, the strength of this effect can be debated, and it may be that it varies between different periods of time and phases of technology. But what is unarguable is the force of the scientific effort produced by the new type of defence industries within the military sector in the period 1880-1914. These years saw a remarkable, "cluster" of weaponry innovations: armour plate; the true machine-gun; quick-firing artillery; the dreadnought battleship; the first effective submarine; the military aircraft. This was, in fact, the *first* modern cluster and it was not replicated until the period 1940-65, approximately, years which witnessed the jet aircraft, radar, atomic weapons, guided missiles and the entire electronic revolution. The periods between the two clusters, and since the second one, have been more concerned with the "follow-on imperative" — refinement of existing weaponry forms — rather than with the "breakthrough" imperative. Or at least this was true until the advent of Star Wars, if that initiative is sustained, or revived, in the new era of detente. Both of the clusters were associated with high levels of military expenditure, international tension, scientific effort, technological change and institutional adaption. It is arguable that "spin-off" effects were pronounced within the cluster periods, less so in the intervening, and subsequent, time-periods.

The Scientific Effort and the Defence Effort, 1880-1914

Clearly, the scientific content of the first cluster of armament innovations needs to be established. The great defence duel of these years, equivalent to the present-day, or recent, contest between the ballistic missile and the anti-missile, was the competition between the big gun and the armoured target.The armour-piercing projectile was the intermediary.

An array of sciences lay behind this competiton. Advances in chemistry were needed to produce the explosive propellants which would drive the projectiles. The need at this time was for higher velocities, in order to achieve greater range and greater penetration, and for less smoke from the explosion, so as to enhance concealment. Nitro-cellulose, or nitroglycerine-based explosives, such as Alfred Nobel's ballistite, or the British Government's cordite[3], both developed in the late 1880s, met this need. Advances in ballistics were necessary to control the flight of the projectile. It was no accident that Sir Andrew Noble, the directing force behind the great British arms concern, Armstrong Whitworth, for much of this period, won his Fellowhip of the Royal Society for mathematical research in this field. Indeed, Noble, who was awarded the Society's Royal Medal in 1880, virtually founded ballistics as an exact science. But, above all, advances in metallurgy were necessary if what the ballisticians calculated to be possible was actually to be achieved with real materials. The manufacture of modern gun tubes, projectiles and armour plate absolutely depended upon major improvements in the performance of metals. In this period, guns ceased to be ingots cast in a solid piece and then reamed out. Rather, they were tubes, wound with miles of steel reinforcing wire and with further tubed sleeves fitted over them, the inner tube being rifled with great precision. In order to withstand the enormous strain of the propelling explosion, these tubes needed to be ductile, but also extremely strong and very flash-resistant. This required the development of a wide range of steel alloys, incorporating nickel, manganese and chrome.

Similarly demanding metallurgical properties were required of the projectiles which were supposed to penetrate plate armour, and not merely fragment on impact. And, of course, the armour itself, in order to withstand such massive blows without cracking, and while denying penetration, needed to be composed of some extremely specialised steels, treated by complex heating and annealing processes. The most successful of these were the American Harvey process and the German Krupp process, both applied for the first time during the 1890s. Of course, once something so hard had been produced, there

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[3] There was a celebrated row about the scientific origins of cordite in which Nobel brought legal action against the Crown and lost by a molecule. See Clive Trebilcock, "A Special Relationship - Government, Rearmament and the Cordite Firms", *Economic History Review*, 19, (1966).

was an added problem: how to cut and shape it. In manufacturing, there is little value in producing a material so tough that it is impossible to work. So, in order to work with armour plate, a new generation of machine-tools and cutting steels had to be produced.

Once all these armaments had become available, they still had to be organised in such a way as to hit the target. Improved optics were needed to produce the visual range-finders which would exploit the reach and ballistic potential of the new guns and propellants. This was an area in which Zeiss created a world-wide reputation before 1914. But even when the approximate distance to target was established, a further task remained: to forecast where it would be by the time a long-range artillery shell reached it. For this, predictor machines were necessary, able to combine statistical variables for range, bearing, speed, and wind-drift and to compute the optimal aim. Premier operators in this field in the 1900s and 1910s were the British admiral, Percy Scott, and the engineer-innovator, A.J.H. Pollen.[4]

Given the possession of the firepower ingredients and the aiming information, the final precondition for a successful shot was a mechanism which could shift the gun into the appropriate posture. Cannon of enormous bulk and weight had to be traversed and elevated with great sensitivity and precision. For this, massive gunmountings had to be constructed. These mountings were very complex exercises in hydraulic and electrical engineering and formed the largest single components of the great battleships of the pre-1914 period, weighing about 400 tons apiece. These were probably the most sophisticated machines of any type operating in the quarter-century before the Great War. In terms of international technological potential, the ability to produce the largest gunmountings around 1910 was roughly equivalent to the ability to manufacture space vehicles around 1980. Only the largest and most scientifically-sensitive engineering works in the world could do this: Krupp in Germany, Schneider-Creusot in France, Skoda in

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[4] See the *Dictionary of Business History*, entry by R. Davenport-Hines; also Antony Pollen, *The Great Gunnery Scandal: The Mystery of Jutland* (London, 1980).

Austria-Hungary, Ansaldo in Italy; and even in Britain in 1910 no more than three manufacturers — Vickers, Armstrong Whitworth and the Coventry Ordnance Works — had the relevant skills.

It is perhaps helpful to take a finer focus upon the detail of armament science. Here a case study is selected from three very different sectors of defence production: one from light weaponry manufacture; one from heavy gun-making; and a third from armour plate fabrication.

a] We now know that the vital manufacturing principle of interchangeable parts, the core of the so-called American System of Manufactures, and the foundation of all mass production engineering, derived not from the work of private innovators such as Colt or Whitney but from forty years of investment by the US Ordnance Department, involving lengthy research into the properties of cast iron and the methodology of gauge testing.[5] The outcome, by the 1850s, was the attainment of machine-produced components that were interchangeable without hand finishing. The impulsion behind this was the military need for swift and relatively unskilled battlefield repair; but the effect was to open access to a vast variety of scientific manufacturing processes. A British military mission to the USA in 1854 tested both aspects. They took at random one rifle from the annual production of Springfield Arsenal for each year between 1844 and 1853, stripped down all ten rifles, jumbled the components, and then picked sufficient pieces, again at random, to make one hybrid rifle of mixed 1844/53 vintage. This proved possible with no more than an ordinary screwdriver; and the weapon fired perfectly. By the 1880s, the rifle shops were the the world leaders in precision standardised manufacturing and the forerunners of a world revolution in mass production. It is difficult to see the results from Springfield as «baroque».

b] In the 1890s and 1900s, a large gun started life as a 100 ton

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[5] M.R. Smith, *Military Enterprise and Technical Change: Perspectives on the American Experience* (Cambridge, Mass, 1985); see also N. Rosenberg (ed.), *The American System of Manufactures* (Edinburgh, 1969) and M.R. Smith, *Harper's Ferry Armoury and the New Technology* (Ithaca, 1977).

ingot of nickel chrome steel. This was an alloy, composed of 30% English and Swedish pig iron, 64% nickel chrome, and small quantities of ferro-manganese and silico-manganese. It cost £ 776, of which £ 600 represented the nickel elements. The alloy was extremely hard, capable of withstanding very high temperatures but also sufficiently expansible to accommodate the enormous strains set up by explosions in the breech of the gun.

The metal was cast into an octagonal ingot, then roughly bored. It was next forged to approximate shape while water was forced through the bored hole so as to maintain the internal dimensions. The forging was then heated to very high temperature in a gas oven and immediately plunged into a vast 14,000-ton tank of cotton seed oil or water for tempering. This tempered forging would go to form the main gun tube. Then a great distance, for a large gun about 120 miles, of 1/4 inch steel wire was wound onto this main tube to form a highly flexible intermediate tube. The next stage was for the outer sleeve tubes to be heated and shrunk on to the wirewound main tube. Rifling the inner tube came next. This was done by internal cutting in an immensely delicate process that must continue without interruption for a period as long as one year. They had to be geometrically perfect if the projectile were to fly correctly and the cutter could not stop without creating dangerous imperfections. The massive machine-tools required for working the gun ingots functioned to tolerances of 1/20,000th of an inch.

These industrial tasks combined,in a unique mixture,refined metallurgy, huge masses of material and minute precision. Few types of civilian heavy engineering worked to such demanding standards.

c] Equally formidable was the manufacture of plate armour.To make a single plate of armour, by the methods of 1896, required doing extraordinary violence to metal. To begin with, an ingot of nickel steel, weighing 52 tons and about one yard in thickness was compressed in a rolling mill, at a single heat, within thirty minutes, to a new thickness of just six inches.This so altered the molecular structure as to enormously increase hardness. Then charcoal was forced into the surface of the metal, under heavy heating, for 10-12 days. This introduced a larger carbon molecule into the already modified molecular structure of the steel. The plate was then bent to the desired shape in a 8,000-ton hydraulic press; then planed, edged and faced to its finished contours. It was these operations which required machine tools and cutting materials of a size, speed and force rarely needed in civilian industry. Once treated to their ministrations, the plate was further hardened by plunging into cotton-seed oil. Then it was alternately heated and water cooled to harden the carbonized belt on the face of the plate, by now some three inches deep. By this stage,the armour was too hard to cut at all, and any final adjustments had to be made with massive grinding machines.

The result was the most advanced metallurgical product of its day. Indeed, one Sheffield armourer was so far ahead of his time — by decades — that he was experimenting as early as 1895 with a tungsten alloy for naval protection.

Armament Industries and Economic Development

What effect did these striking developments in armament science have upon the general process of economic development? The answer might be split into two parts, both focused upon the time frame 1900-1914. The first deals with the impact of armament innovation upon the technologically-advanced economies of the day, such as Britain, Germany, France or the USA. The second considers the effect upon the economically developing or "less developed" economies of this period, such as Russia, Japan or Italy. The entire problem is also subject to the reservation that it is not simple to track the "spin-off" of a single innovation from the military to the civilian sector of industry or to spot the "trickle down" of an individual piece of information or process. And there may also be resistance within the receiving sectors. It can be easier to show that a potentially useful innovation was generated in the defence sector than to demonstrate that the utility was perceived in the non-defence sector.

Nevertheless, the examples already cited do suggest that armament firms and arsenals were the scientific leaders among the industries of the big economies. Vickers and Armstrong maintained research facilities that were matched by few commercial producers, while the scientific application of the explosives industry clearly outstripped that of the UK chemical sector as a whole. In the great debate about the shortcomings of the late nineteenth-century British economy, it does at least seem to be common ground that the level of industrial science — for whatever reason — was low. In the British defence industries, imperial commitments required that matters were otherwise. In Germany, industrialists in many sectors were far more sensitive to the industrial yield from scientific investigation, and nowhere more so than in the steel industry. Yet even here, Krupp stood out. According to the English steelmaster, Sir Robert Hadfield, the Essen armoury boasted research facilities that were far superior to those of any university in Europe.[6]

In some cases, the outcome was clear: the transfer of innovations from the scientifically-active armament producers into more general industrial applications. Thus nickel steel passed into heavy-duty civilian use in shipbuilding and marine enginering and nickel alloys into motor-car engineering. Much of the pioneering work in high-speed machine-tool steel — vital for working armour plate and gun steels but also the parent for a whole generation of civilian machine tools — was carried out in Britain by armament firms such as Armstrong and Firth. Significantly, Britain retained competitiveness in heavy machine tools long after she had surrendered the field in light machines to the Americans.[7] The different military specializations of the British on heavy naval weaponry and the Americans on light, mass-produced firearms was not irrelevant to this.[8]

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[6] Cited in H. Hauser, *Germany's Commercial Grip on the World*(London, 1917), p. 43

[7] S.B. Saul, "The Market and the Development of the Mechanical Engineering Industries in Britain, 1860-1914", *Economic History Review,* (1967).

[8] The superiority of the British in heavy naval shipbuilding and the associated defence engineering trades was such that the US Secretary of the Navy considered seriously the prospect of attracting Vickers to the American East Coast around 1900 in order to set up a leading-sector armoury which could act as a guide to the nascent American capacity in this category of weapons. See Clive Trebilcock, *The Vickers Brothers: Armaments and*

The contribution of the rifle-makers of all nations, but particularly the Americans, to general engineering practice need hardly be laboured. One of the central industrial strategies of the modern era — "mass" or "flow" or "standardized" production — came out of the small arms factories. Certainly, rifle manufacture introduced the principle of interchangeability, combined with heavy output, to British industry. In Birmingham, rifle production was the first industry in which standardized engineering led to increased scale of plant. And, throughout Europe, arms-makers were attracted by their skills in repeat and precision manufacture to leading-edge civilian technologies, such as bicycles and automobilies. Here they became star performers. The whole range of tube, steel and standardization technologies needed by BSA to produce rifles formed, as the firm's Chairman argued, "a unique recipe for success in the cycle trade".[9] Vickers possessed its own motor-car subsidiary, Wolseley, produced special steel for it, built many of its machine tools, used Wolseley to make high-powered submarine motors, and applied the lessons learned to car production. By 1910, Vickers was carrying out steel work for some twenty-five automobile producers. One contemporary journal went so far as to argue that "Cycles and motor-cars owe their development to the mechanical perfection which grew out of satisfying war requirements".[10] It was not accidental that, by 1914, two of the three most successful automobile firms in the UK were owned by armament concerns: Vickers controlled Wolseley; BSA controlled Daimler.[11]

On the other hand, the needs of the developing economies of the pre-1914 world were scarcely to be met by the promotion of leading-edge sectors of the bicycle-automobile variety. The technology gap in such economies between these sectors and the bulk of their low-order manufacturing was too wide for effective transfer of innovations to be possible. However, economies like Russia, Japan or Italy did need to develop capital goods industries such as steel,

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Enterprise 1855-1914 (London, 1977), pp. 135-9.

[9] B.S.A. *Chairman's Annual Report, 1910.*

[10] *Arms and Explosives,* March 1914

[11] More detail on these issues is provided in Trebilcock, "Spin-off".

engineering or shipbuilding. Yet, notoriously, less developed economies lack the markets for capital goods, which are the essential supports for the development of the heavy industrial sectors. Here, military demand may act as one of the few guaranteed sources of demand for capital goods, the armed services forming one of the few markets for quality metals and complex machines.

Less developed states often insisted upon the acquisition of advanced armament industries before their less developed economies had progressed far with the construction of advanced civilian industries. In the pre-1914 era, strategic considerations often promoted the importation of high-quality defence processes from larger economies, and this could raise standards in a wide range of indigenous industries required to provide inputs for the new armament industries. In Russia, in the 1900s, the presence of modern armouries, advised by foreigners, set new specifications for Russian engineering and steel producers.[12] In Italy, naval demand virtually created a competitive shipbuilding industry and constituted the market for the infant Italian steel industry of the 1880s.[13] In Japan, the modern arsenals of the 1880s and 1890s were centres of machine skills which turned out not only weaponry but advanced western-style machinery for the cotton textile industry.[14]

Within economies of this type, the creation of best-practice defence industries, often for political reasons in weak and strategically-vulnerable states, had repercussions far outside the sphere of the military. Regimes that were not especially friendly to modern technology on politico-social grounds, would accept it for the military gain it represented. The implications for longer-run economic development were substantial.

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[12] See Trebilcock, "British Armaments".

[13] R.E. Webster, "Industrial Imperialism in Italy, 1906-14 (Berkeley, 1975), pp. 77, 96-7, 106-116; also S.B. Saul, "The Nature and Diffusion of Technology" in A.J. Youngson (ed.), *Economic Development in the Long Run* (London, 1972), pp. 48-55.

[14] K. Yamamura, "Success Ill-Gotten The Role of Meiji Militarism in Japanese Technological Progress", *Journal of Economic History,* 37, (1977); but see also A.C. Kelley and J.G. Williamson, *Lessons from Japanese Development: An Analytical Economic History* (Chicago, 1974).

In this model, then, imported defence technology of an advanced type creates markets for capital goods where they were previously lacking, and raises skill levels, less in leading-edge industries, than in the key basic industries required in the early stages of late-nineteenth or early-twentieth century growth.

So, in the case of the advanced economy, armament science confers technological quality; in the case of the developing economy, it creates more general demand and learning effects.

The Balance Sheet of Armament Science

The objections to the mode of thought so far advanced in this paper are powerful and familiar. Though expressed in many different ways, they may be reduced to two basic propositions: that military spending is essentially unproductive and, therefore, "wasteful"; and that there must be a cheaper, and more productive, way of achieving the same technological effect without recourse to the military budget.

There has been much loose thinking on the unproductive nature of military spending. Often, it is assumed that the whole military budget is subject to considerations of opportunity cost: in other words, that we could — and often, implicitly, should — spend all of what we actually spend on the military on other, more humane, end-uses. So the opportunity cost of submarines is lost schools, of helicopters missing hospitals. But, in reality, not all military expenditure is subject to opportunity cost. Some of it represents the true cost of security, the price needed to deter an opponent from aggression. This part of military expenditure is not a burden on the civilian economy but a requirement for its peaceful survival. So, properly understood, the element of military expenditure which is vulnerable to considerations of opportunity cost is the excess that is spent over and above the necessary cost of security. For, of course, it is entirely possible, indeed quite common, to over-spend on the military. On the other hand, it is exceedingly difficult to pitch expenditure precisely on the real cost of security. One side knows for sure that it has under-spent only when the other side's tanks are in the palace compound. In this sense, there is both a gross and a net investment in the cost of security, and wisdom consists in getting as close to the net as is safe.

Furthermore, the true net cost should be further reduced by the value of the other utilities produced by defence expenditure. Positive economic effects of at least three types follow from military spending and these too should be defrayed from the "burden". They are: a] the technological gains which are "spun off" from military research; b] the direct employment generated by production in the defence sector of industry; c] the multiplier effect within the civilian economy deriving from the "public works" aspect of military investment.

So the "burden" of military expenditure will be a great deal less than the amount of the total defence budget.

Secondly, we confront the proposition that any technological success achieved through the military budget is "success ill-gotten". The implication, of course, is that any technical gain achieved through armament effort could have been "gotten" more productively, through alternative non-military means. Again, there are problems about this. It is not clear, for instance, that the line of invention can be varied with such impunity and perhaps should rather be treated as an historical given. Counter-factual propositions in regard to the sequence of invention inspire little confidence. No-one can really guess what, if the railway had not been invented, the "alternative" series of water-based inventions might have looked like. Similarly, if repeat-interchangeable production had not come about through 40 years of research by the US Bureau of Ordnance, it is hardly productive to speculate as to what other body might have been able or willing to invest this amount of time and research in it [or for what reason].

This gives emphasis to an earlier point: military authorities undertake research of a different kind from that of the majority of the civilian sector. Military-sponsored research contains more "pure", open-ended and long-running programmes. Alternative sponsors for these types of programme are rare. If major investigations spring from these sources — as many have — it is not easy to suggest through what other channels they might have come.

Nor is military funding itself as easily re-directed as is sometimes assumed. Propositions to the effect that military spending would be better spent if switched to more immediately constructive social projects assume implicitly that military funds are freely convertible into other government "currencies". This is an heroic assumption. In autocratic or authoritarian political systems, of course, it is simply inapplicable: the political sociology of such regimes attributes high priorities to military activities and low ones to such objectives as social welfare, education, etc. Even in democratic or constitutional political systems, the community has displayed over time a greater willingness to be taxed for its own defence than for most other purposes. Sadly, it is easier to gather fiscal resources for the science of nuclear submarines than for the science of pollution control, environmental protection or alternative power sources — or at least it has been until very recently. It seems to be the case that there are stronger institutional and electoral constraints upon non-military expenditure by governments than upon the spending of their military agencies.

The "alternative scenario" in which the gains actually derived from militarily-funded armament science are obtained by some other, more peaceful means is thus vulnerable to two substantial objections: a] that the "better" route to the same necessary scientific advances is not specified and is perhaps impossible to specify; b] that major frictions and rigidities in the way real world institutions and communities function have to be discounted in order to create the unreal fluidity of resources which is required to fund the alternative scenario.

One implication of this mode of thought is relevant to the "peace dividend" that is promised to the era of the new detente. The arguments sketched above would place limits upon the size of this dividend. Just as there were both gross and net costs of security, so there will be gross and net dimensions to the peace dividend. The real saving will not be the total clawed back from reductions in weapons programmes or military establishments. This total will be reduced by the value of the scientific innovations foregone in consequence of the reductions in defence-based research and development, or by the cost and difficulty of devising quite new methods of supporting large areas of "pure" research. There will be employment losses in both factory workforces and scientific manpower. Costs sunk in refined manufacturing equipment will not be easily recouped as these machines prove difficult to redeploy.

On the other hand, certain types of defence research will need to continue. If there will be less place for the nightmare weapons which succeeded for more than four decades in deterring super-power conflict, there will still be need for the "smart" weapons which appear to have found a special role in deterring the aggression of lesser despots. It is worthy of note, for instance, that the Patriot anti-missile system, which served with distinction in the Gulf War of 1991, was being developed as part of the Strategic Defence Initiative or "Star Wars" programme of the USA. [15] Thus a scheme much-criticised for its science-fiction extravagance produced a missile which succeeded in defending Israeli and Saudi Arabian cities from an up-rated version of a terror weapon nearly a half-century old. [16] Patriot suggests that the new detente will continue to need some extremely refined armaments of particular types and that continued scientific effort will be required to produce them.

There is,of course, no respectable argument for spending more on defence science in order to obtain the technological gains for the civilian economy. And nothing of the sort is suggested in this essay. What is proposed here is that we should acknowledge the scientific and technological successes which, in certain phases of the past, have derived from defence programmes, and lay proper doubt upon the blithe counter-factual assumption that they could have been derived, easily or cheaply, from somewhere else. And we should be careful of the exaggerated savings that we are offered from spending less on military science. We shall have to work hard and ingeniously if we are to obtain a genuine part of them.

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[15] *International Defence Review,* 24, May 1991, p. 457. I am grateful to Sue Parker of Jane's Information Group for this reference.

[16] The Scud B is a not-so-distant relation of Hitler's V2 rocket.