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DEFENSE R&D AND INFORMATION TECHNOLOGY IN A LONG-TERM PERSPECTIVE

LA RD MILITAIRE ET LES TECHNOLOGIES DE L'INFORMATION EN LONGUE PÉRIODE

Renaud BELLAIS

ABSTRACT – Defense R&D is usually considered as an economic burden, implying an eviction effect on civilian R&D and perverting the national systems of innovation. If arms production benefits nowadays from advanced civilian R&D, the flow of technology was not always in the same direction–especially in the 1950s and 1960s. Moreover, since the beginning of the 1990s, some technologies, classified for a long time as purely defense ones (GaAs, GPS, computer networking, etc.), have found new civilian applications.

Why technological opportunities created by defense R&D are not systematically seized by commercial firms? First, technology transfers come true only when a legal framework exists and allows commercial firms to get access to the "military technological fund". Second, the global economic context appears as the greatest incentive to engage civilian firms in exploiting defense technologies, as an investment opportunity. In a long-term perspective, when specific conditions are set up or exist, defense R&D can become a means of strengthening the international competitiveness of national economies.

RÉSUMÉ – La RD de défense est souvent considérée comme un fardeau pour l'économie, impliquant un effet d'éviction sur la RD civile et pervertissant le système national d'innovation. Si la production d'armements profite aujourd'hui des avancées de la RD civile, le flot de technologies n'a pas toujours été dans la même direction – tout particulièrement dans les années 1950 et 1960. De plus, depuis le début des années 1990, quelques technologies, longtemps classées comme purement militaires (GaAs, GPS, réseaux informatiques, etc.), ont trouvé de nouvelles applications civiles.

Pour quelles raisons les opportunités technologiques créées par la RD de défense ne sont-elles pas systématiquement saisies par les firmes commerciales ? Premièrement, les transferts de technologies se concrétisent seulement quand un cadre légal existe et autorise les firmes commerciales à avoir accès au "fonds technologique militaire". Deuxièmement, le contexte économique global constitue une incitation importante pour engager les firmes civiles à exploiter les technologies de défense. Dans une perspective de longue période, quand les conditions idoines sont mises en place ou existent, la RD de défense peut ainsi devenir un moyen de renforcer la compétitivité internationale des économies nationales.

Defense R&D and Information Technology in a Long-Term Perspective

Renaud BELLAIS*

1. Introduction

Defense R&D and arms production are usually considered as unproductive activities, implying an eviction effect on civilian R&D, other public expenditures and even a perversion of the whole economy. One decade after the end of Cold War, in absence of major conflicts or threats, the military effort is widely perceived as a heavy and useless burden on national economies. In the major arms-producing countries (i.e. the United States, United Kingdom, France, Russia and Germany), defense R&D has especially drawn critics. Indeed the place of defense R&D in the national systems of innovation is even greater than the place of arms production in the economy. For instance, defense research absorbs in France nearly 30% of the national R&D effort, while arms production does not represent more than 5% of industrial production. Such a weight is not without consequences on the functioning of the national system of innovation.

Moreover defense R&D differs from civilian one. It has its own aims, which are often incompatible with those of civilian activities. Econometric and empirical studies have shown that defense R&D has a very small impact on economic productivity (Lichtenberg, 1995). This is why many people suggest to reduce or even suppress such an expenditure, and redirect these credits to civilian R&D. However one can wonder if this analysis reflects all the impacts of defense R&D on the civilian economy, especially in a long-term perspective. Benefits from defense R&D have not been satisfactorily assessed. Measuring "spin-off" has always been difficult, since military technology is extremely diverse and ranges across many industrial sectors.

In order to assess the long-term relationship between defense R&D and civilian technologies, this paper focuses more specifically on information technology. The relationship between defense R&D and information technology is particularly interesting since information and communication systems are in the heart of weapons systems and constitute a raising share of military procurement since the 1960s. It is thus one of the rare budgetary items that have escaped from budget cuts (since the end of Cold War).

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Moreover military R&D and procurement played an essential role in the rise of information technology in the 1940s and 1950s. If services' leading role is widely recognized in the first decades of information technology (integrated circuits, first computers, computer science, etc.), it is often stated that their influence declined progressively–transforming defense R&D, once an engine of growth and scientific progress, in a useless and quite heavy burden. Is the military unable to support the most promising technologies? Does defense R&D fail to make good choices among possible technologies, i.e. those offering the greatest social return?

In order to analyze the relationship between arms production and information technology during the last fifty years (from ENIAC to Internet), it is interesting first to survey what kinds of critics are made towards arms production in general and defense R&D more especially (section 2). Then three examples of "defense-born" technology will be surveyed: the Global Positioning System, gallium arsenide integrated circuits, and computer science, with a particular interest on network systems (section 3). This survey aims at showing that a too global presentation can mask more interesting trends, which can have a huge impact on civilian technologies. These elements will lead to a more global analysis about long-term relationships between arms production and the history of technology (section 4).

2. Defense effort and economic decline?

While the entire world was enlisted in a gigantic arms race in the 1980s, many studies came through about the macroeconomic impact of this budgetary and industrial effort. They threw into relief that military expenditures reduce economic growth and even undermine the competitiveness of national economies. Defense R&D was particularly criticized.

However government-funded R&D is most of time perceived as the engine of long-term growth, since it complements and amplifies commercial firms' investment in research. This difference results from the specificity of defense R&D that radically differentiates it from government-funded research in civilian activities. Even worse defense R&D seems to lock in national systems of innovation to inefficient behavior and inadequate technologies. The example of information technology is often chosen to show how services' interest in a technology can reduce its economic potentialities to nothing.

2.1 *Social return to public R&D*

Even after an impressive fall in the last years, defense R&D still represents a huge share of government-funded R&D in arms-producing countries (Table 1). This trend is very specific to the period starting in the 1940s. As World War II demonstrated the potentialities of scientific and technical progress, States began to dedicate important budgets to public research in most industrial countries. This was a major change, which has given birth to what Freeman and Soete (1997) called "Big Science". For instance R&D credits in the United States represented only 0.8% of the federal budget in 1940, but more than 10% in 1960. It was defense R&D that received most of this increase, and it still represents a major share of public R&D in the 1990s.

Such a dedication proceeded from major successes in defense R&D like the "Manhattan" project. As Väyrynen (1983) states, "the invention of atomic bomb modified entirely the importance of technology towards national military policies" (p.63). Even General Eisenhower–eventually a leading opponent of the "military-industrial complex"–asserted in a 1946 memorandum that scientific and technical progress was essential for the national security.[1] Nevertheless the greatest advocate of defense R&D was unquestionably Vannevar Bush. In *Science, The Endless Frontier*, he popularized the idea that government-funded R&D produces large technological spin-offs. His book reveals how numerous are the technological opportunities engendered by the war effort and argues that it is fruitful to keep on with in peacetime. Vannevar Bush created a founding myth, which soon became the justification of government-funded R&D (both military and civilian).

Table 1 – Defense share in government-funded R&D credits in main OECD countries

country	1991	1997
USA	59,7%	55,0%
United Kingdom	43,9%	37,7%
France	36,1%	27,7%
Sweden	27,3%	20,9%
Spain	16,8%	19,6%
Germany	11,0%	9,6%
Italy	7,9%	4,7%
Japan	5,6%	5,8%

Source: "OECD in Data", supplements to *The OECD Observer*, various issues.

In the 1960s, economics gave a theoretical ground to government-funded R&D. Many studies have shown two complementary trends: government-funded R&D has a greater social return than private R&D; firms tend to underinvest in R&D since they cannot capture all its economic value. Empirical literature evaluates the rate of return to R&D from 30% to over 100%, supporting the idea that there is too little private investment in research. For instance Jones and Williams (1997) evaluate that "using a conservative estimate of the social return of 30% and a private rate of return to capital of 7%, optimal R&D spending as a share of GDP is more than four times larger than actual spending" (p.3).

All these elements put the conditions for States to be involved in a huge R&D effort. Information technology has attracted a large part of public credits, not only because it was a promising field, but also because of services' need in advanced systems and technologies. Indeed, "the development of increasingly sophisticated weapons systems means that virtually every aspect of current military technology depends on microelectronics" (GAO, 1986, p.9).

Nevertheless nothing was said about the different targets of government-funded R&D. Actually economic impacts of such expenditures depend on their aims, and defense ones are quite specific and narrower than civilian ones. The analysis of military technology is distinctive in a large part of the literature for a specific reason: although firms are the main technology holders, States remain the main financiers of military innovation, and the sole purchasers of weapons systems.

As shown in Table 2 defense R&D is essentially devoted to development and realized by firms themselves while civilian and government-funded R&D focuses more on basic or applied research; and the latter is realized mostly by university and research centers. Such a concentration of R&D on development stages reduces the social return of research effort:

[1] D. Eisenhower, *Memorandum for Directors and Chiefs of War Department General and Special Staff Divisions and Bureaus and the Commanding Generals of the Major Commands on Scientific and Technological Resources as Military Assets*, April 27, 1946.

more R&D focuses on specific applications, less it is likely to have an important social return. Fontanel (1997) notes that firms get about 70% of public funds in most of arms producing countries. Such an affectation has strong implications on the economic potentialities of defense R&D that differs from the general analysis of such public expenditures.

Table 2 – Department of Defense R&D in Fiscal Year 1999 (millions of dollars)

category	amount	percentage
research, development, test and Evaluation		
basic research (6.1)	1,108	2,9%
applied research (6.2)	3,151	8,3%
total research	4,259	11,2%
advanced technological development (6.3)	3,532	9,3%
total science and technology	7,791	20,5%
demonstration/validation (6.4)	7,237	16,1%
engineering and manufacturing development (6.5)	7,931	20,9%
RDT&E management support (6.6)	2,930	7,7%
operational systems development (6.7)	11,516	30,4%
total RDT&E	37,405	98,5%
other appropriations	570	1,5%
total DoD R&D	**37,975**	**100,0%**

Source: American Association for the Advancement of Science, <http://www.aaas.org>.

If public R&D in general seems to have a high level of social return, what can be said about defense R&D? Econometric studies give a sad picture: defense R&D appears to offer a truly lower rate of return compared to civilian one. Many surveys even suggest that, holding non-defense R&D constant, defense R&D has essentially no effect on productivity growth. The apparently low social rate of return to government-funded R&D should be interpreted with caution; but Lichtenberg argues that "even if the negative sign of this coefficient is not surprising, however, its magnitude is of interest, since it indicates the opportunity cost (in terms of conventionally measured output) of government-funded research" (p.447).

Lichtenberg's various studies lead to one conclusion: defense R&D does not tend to stimulate civilian R&D and it does not have a direct or indirect positive effect on productivity growth. Then it seems that defense R&D constitutes a truly useless expenditure and an economic burden reducing economic growth (and growth potential). Therefore the economic argument in favor of government-funded R&D seems not to apply to defense research.

2.2 *Military requirements and technological lock-in*

If defense R&D does not have the supposed huge value of civilian one, can it have even so a positive impact on economic growth? Indeed most results of specialized R&D programs go to their own field and have a low impact on other fields. However it can lead to generic works, which constitute the ground of more targeted research. What can we say about defense R&D?

The military is willing to spend a lot to achieve marginal improvements, through incremental innovations, for a "small edge in performance can mean survival" (Alic *et alii*, 1992, p.114). Efforts are often concentrated on marginal increase of technological performance, which absorbs a large share of credits but have a very low social return. Leave well alone: military requirements are based on what the state-of-the-art allows, rather than on what would be "acceptable". Technological performance must be reached whatever its cost, as the cost constraint is much lower than in civilian activities. As Gansler (1989) puts, "we have what refer to as the technological imperative: because we can have it, we must have it" (p.217).

Moreover the services tend to resist new technology that requires changes in their roles and missions. Thus, technological advancement creates a dialectic conflict. On the one hand, "technological opportunities resulting in incremental changes are rapidly accepted and enthusiastically pushed forward–perhaps too unquestioningly" (Gansler, 1989, p.218). On the other hand, services resist to revolutionary changes coming from outside, and often reject them even if they outmatch technologies which are used in current weapons systems. Parochial interests–both in the military and defense firms–lead to incremental innovations that perpetuate state-of-the-art technology. As James Schlesinger once said, referring to the US Department of Defense, "large hierarchical organizations tend to be remarkably efficient mechanisms for the suppression of new ideas and alternatives".[1] As Kaldor (1981) puts, defense R&D tends to "mummify" technologies because of an overspecialization and very narrow aims.

In the defense world, as well as in any technological quest, costs have risen along with. The 5 or 10% of additional performance results in at least a 30 or even 50% increase in cost. The resulting price drift reduces little by little the quantity of weapons systems a country can afford. This trend drives prices even higher–without speaking of ever more numerous problems during development stages... The development cycle of new weapons becomes undoubtedly longer and longer. When life cycle of commercial equipment is about 4-6 years, weapons life cycle goes beyond 10-12 years. The logical consequence of this trend is that weapons systems are more and more based on outdated technologies: "the complex designs created in the quest for high performance result in low-quality production, and high rejection rates in the production process lead to high production costs" (Gansler, 1989, p.219). When weapons systems arrive in field, they are sometimes several generations behind application in civilian markets.[2] This is particularly true in semiconductors, and it becomes more and more complicated for militaries to find spare parts, as it is usual that production lines do no longer exist!

In addition to this development bias, defense R&D is realized in a special context far from market conditions. Several observers criticize this "logique d'Arsenal". Indeed criteria differ between commercial and defense productions. While commercial firms focus on price and cost reduction, services consider technological performance as more important than cost minimization (or productivity). Such a context induces a drift: military products are more expensive, more specialized and have a greater technological efficiency; but such productions appear economically inefficient. This context could be harmless if it were confined to arms production, but Kaldor (1981), DeGrasse (1983), Chesnais (1990), Fontanel (1997) and many others suggest that it is not the case. As arms production takes place in the heart of national economies and systems of innovation, this production influences not only arms-producing

[1] Quoted in J. Canan, *The SuperWarriors: The Fantastic World of Pentagon Super Weapons* (Weybright and Tulley, 1975), p.106.
[2] For instance, the 256K DRAM was in the saturation stage of product life-cycle for civilian use in the middle of the 1990s, but it was still in the maturity stage for military applications (Cowan and Foray, 1995, p.865).

firms (and their suppliers), but also other firms by an imitation effect (project management, R&D targets, scientists, engineers and workforce behaviors, etc.).

Military requirements can lock in the national system of innovation to inferior technology paths. The US nuclear industry provides a famous example. The latter is dominated at almost 100% by light-water reactors, a technology originally adopted by the US Marine in the 1950s. The leading role of defense R&D and procurement at this time acted to widely favor light water. Arthur (1989) explains that "learning and construction experience gained early on appear to have locked the industry in to dominance of light water and shut other reactor types out" (p.126). Even if defense R&D allowed and accelerated the development of this technology (and activity), the initial choices limit the following ones. It does not matter if one could certify that these initial choices are the best, but we are far from this. Much of the engineering literature contends that, given equal development, the gas-cooled reactor would have been superior. The history of a technology determines its forthcoming developments and stalemates.

Therefore defense R&D appears to be overspecialized, engendering overcomplicated system with performance requirements that are not relevant. The way arms production is realized leads to particular behaviors, which are irrelevant into market mechanisms. Defense R&D seems then harmful in regard of both technological and economic criteria. Warren Davis once even said that overspecialization in defense R&D and arms production represents "the kiss of death in fields in which entire technological revolutions take place on the order of every five years."[1]

2.3 *From 1950s to 1980s: the declining usefulness of defense R&D*

"The 20th century began as it is ending, notes Walker (1994), with military innovation playing a secondary part in the evolution of technology, taken in the round." (p.198) Actually defense R&D and procurement played an essential role in the post-war period. By offering many funds to research and markets for emergent activities, military effort allowed the development of electronics, computer science, aerospace, machine tools, etc. In a seminal paper on industrial policy, Reich (1982) states: "Large scale defense and aerospace contracts have provided emerging industries in the United States with a ready market for which they have expanded production and thereby gained valuable experience, know-how and scale economies. The Pentagon's willingness to pay a high premium for quality and reliability, moreover, has helped emerging industries bear the costs of refining and 'debugging' their products." (p.864)

However this influence evolved from the 1950s to the 1970s. The example of microelectronics can throw into relief such an evolution. Even if transistor was not invented in military laboratories or by defense contractors, it is obvious that what permits this discovery to become an industrial reality is the defense market. Indeed as services were interested by this discovery, they gave many R&D credits in order to develop concrete applications (Misa, 1985). Thus military orders were the first major market for transistors. Other examples are well known. First computers and computer languages were based on research financed by military projects–especially Whirlwind and SAGE.

Since the 1960s, Defense R&D seems however to lose its efficiency and leading role in the development of information technology. Civilian spin-offs were smaller and smaller meanwhile military research required more and more time (and money) to fulfill its scientific

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[1] W. Davis, The Pentagon and the Scientist *in* J. Tirman (ed.), *The Militarization of High Technology* (Cambridge, Massachusetts: Ballinger Publishing, 1984), p.159.

and technical targets. It seemed that defense was no longer the technological engine it had been during the 1950s and 1960s. Even worse the completion of many projects becomes only possible thanks to civilian technologies.

Apparently arms production has progressively become a burden to the civilian economy. The scientific and technical failure of defense R&D appears like a curse on every activity concerned by arms production. Such a trend seems to be a consequence of an endless quest for incremental improvements of technological performances. Norman Augustine, then president of Lockheed, estimated that the last 10% of performance costs one-third of the total costs of weapons systems and causes two-thirds of the total problems. One can add that in many advanced systems, the ratios come out even higher. Many studies show that weapons systems built with commercial components would have lower overall costs (by a factor from 2 to 8) while having comparable or even better reliability. As arms production tends to evolve in isolation, it produces expensive systems which have performances useless outside military context. As shown in Table 3, military requirements have pushed information technology in a path that is not compatible with civilian demands: high cost, longer and longer development cycles, and unneeded technological performances.

Table 3 – A comparison of "milspec" and commercial semiconductors (comparable part, comparable environment)

		"milspec"	commercial
part cost:	bipolar digital logic	$15.78	$1.67
	bipolar linear	$11.40	$0.42
reliability failure index		1.9-4.6	0.06
lead time for new parts (months)		17-51	1-12

Source: J. Gansler, *Affording Defense* (Boston, Massachusetts: MIT Press, 1989), p.232.

Moreover services have gradually lost their influence on information technology when civilian markets enlarged. If the US Department of Defense and NASA were the largest purchasers of semiconductors until the late 1960s,[1] Kubbig (1986) notes, their influence substantially faded in the 1970s: "The government's share of semiconductor output decreased from 36 per cent of the total in 1969 to about 10 per cent in 1978." (p.208) As defense R&D focuses essentially on incremental innovations and the civilian economy has evolved in its own way, the generic similarity of military and civilian technologies has declined. In microelectronics, arms production has become more and more dependent since the end of the 1970s on technological advances realized outside defense R&D.

Kaldor (1981) shows that defense R&D engenders a "baroque Arsenal", i.e. less and less appropriate weapons systems with "gadget" performance. Whereas King Midas transformed everything he touched in gold, whatever technology services are interested in it is unavoidably condemned to decay because of their "bad" influence. "Rather than encourage commercial development, notes Reich (1982), defense spending on emerging high technologies may therefore have the opposite effect over the long term, diverting US scientists and engineers away from commercial applications." (p.870)

[1] In 1962 almost 100% of integrated circuits demand was military.

3. Defense R&D and information technology in a long-term perspective

According to the "crowding-out" argument, defense R&D weakens the competitiveness of countries, as military programs take over a huge share of public credits which otherwise could be allotted to civilian projects. Many economists argue that the positive impact of defense R&D on the civilian economy has declined significantly since the 1960s; and that it has occurred a kind of reversal of technological flows between them.

Although this presentation reflects the global tendency, does it present the entire picture? One can wonder if defense R&D has lost any influence on technological progress. Actually it is necessary to place our analysis in a long-term perspective, and it appears that defense R&D gives still birth to major spin-offs. Three examples illustrate this phenomenon: the Global Position System, gallium arsenide integrated circuits, and computer science.

3.1 *Global Positioning System, military roots and civilian promises*

The Global Positioning System (GPS) is a US military space system operated by US Air Force, composed of a space segment (a constellation of 24 satellites that broadcast precise time signals) and a control segment (a control center and overseas command stations). GPS provides signals that aid position-location, navigation and precision timing based on specific algorithms. This system is a good example of a system built by the army for its unique use. The US Department of Defense developed GPS, since armed forces are increasingly reliant on such signals for various purposes–from navigation to munitions guidance. As American forces must be operational worldwide, GPS initial aim was to provide them latitude, longitude and time measures with the greatest precision whenever and wherever on the globe.

When built it was not expected that GPS could have civilian applications. Its utilization was 100% military, and the investment entirely supported by the services. During ten years (1974-1984), armed forces were the only GPS users, but this system has evolved far from its military origins. It is now a worldwide information resource supporting a wide range of civil, scientific and commercial functions, from air-traffic control to Internet.

GPS has also spawned a substantial commercial industry in the USA, but elsewhere too, with rapidly growing markets for related products and services. Its openness started in 1983, when President Reagan allowed civilians to access this system (following the destruction of an airplane of Korea Airlines by the Soviet army). Actually civilian uses of GPS effectively began in 1988, with the launching of constellation Block II and the development of commercial applications (GAO, 1994).

Civilian applications have multiplied. Civilian public agencies and scientific institutions formed the first non-military markets, but it was when commercial applications appeared that sales exploded: navigation systems, agricultural and forestry management, car navigation, avionics (especially landing systems), management of communication networks, geological survey, and so on. Nowadays arms-producing firms can exploit the knowledge and know-how acquired in the development of military systems in order to offer commercial GPS products. Moreover the free access to many defense-sponsored researches allows many firms to enter this emerging market.[1]

[1] The rise of civilian GPS systems was made easier by the fact that GPS access is free of charge. The only requirement to use this system is to purchase adequate equipment. Therefore the existence of a public infrastructure managed and financed by the military constitutes a major explanation of the "GPS boom".

A vast market opened from a once purely military technology. While in the 1980s GPS market were almost 100% military, civilian applications represent nowadays more than three-quarters of GPS activities. Table 4 shows that civilian applications overwhelm military ones now: in 1993, the latter represented no more than 6% of this market, and its share is expected to drop around 1,5% next year. An 8:1 ratio is expected by the beginning of the 2000s (Pace *et alii*, 1995). Even more the US General Accounting Office assumes that 95% of the potential is still to discover (GAO, 1994). Here boom in civilian demands results in scale and scope economies, which in return accentuate the civilian demand... by reducing the price of GPS tools.

This evolution of GPS market is quite unexpected and it can surprise the observers who criticized it in the 1970s (and even in the beginning of the 1980s). This entire change results from the free access to GPS, but that is not enough to understand the enlargement of civilian applications. The rise of commercial market can be linked to the apparition of new needs. These latter correspond mainly with the development of electronic-intensive commercial items. The best example is in the automobile market: for two or three years, new models of car have incorporated an ever-greater number of electronic items. Cars become interconnected products, increasingly using software applications. In the early 1990s, such tools still appeared as "gadgets", with a market limited to luxury cars. Today most car producers offer these items even in series cars, for they increase their safety and utilization comfort. GPS market has benefited and still benefits from such an evolution.

Table 4 – Global GPS Projections

millions of dollars	1993	1994	1995	1996	1997	1998	1999	2000
car navigation	100	180	310	600	1,100	2,000	2,500	3,000
consumer/cellular	45	100	180	324	580	1,000	1,500	2,250
tracking	30	75	112	170	250	375	560	850
original equipment manufacturer	60	110	140	180	220	275	340	425
survey/mapping	100	145	201	280	364	455	546	630
geographic information systems	25	35	50	90	160	270	410	650
aviation	40	62	93	130	180	240	300	375
marine	80	100	110	120	130	140	150	160
military	30	60	70	80	90	100	110	130
TOTAL	**510**	**867**	**1,266**	**1,974**	**3,074**	**4,855**	**6,416**	**8,470**

Source: S. Pace *et alii*, *The Global Positioning System, Assessing National Policies*, Critical Technologies Institute, Santa Clara (California), RAND, 1995, p.104.

3.2 *Gallium arsenide, the unexpected civilian applications*

Gallium arsenide, according to a well-known aphorism, is the technology of the future, always has been and always will be! This is how this technology has been appreciated for decades. One considers sometimes that services request unsustainable demands, so that weapons systems look like high-tech gadgets with useless performances. Gallium arsenide (GaAs) integrated circuits and related products were long considered as expensive military "gizmos".

Silicon is the mainstream semiconductor material, even if it is not the only semiconductor material. Most of electronic components are based on silicon, as this technology benefits from scale and scope economies (in both research and production). As many products employ silicon, the cost of silicon components is low and the development of new items needs only additional research. This is why alternative semiconductor material does not attract many researchers[1] (and research credits). However silicon potentialities are not infinite. As requirements increase, the limits of silicon appear and other semiconductor materials can become attractive. Then the main problem is that developing a new technology is very expensive compared with improving the old one. This is the reason why it is necessary that the requirement constraint is sufficiently high to finance such a research.

These specific constraints are especially strong for communication systems. Even if the properties of GaAs were known for ages, cost constraint and low performance needs prevented civilian firms from exploring its potentialities. Contrary to the civilian demand, services looked for communication equipment with high performances in the 1960s and GaAs was more appropriate than silicon for strong requests. Weapons systems must be employed in specific environments and resist to radiation or long periods of utilization.

It is not difficult to understand why research on GaAs has been funded mainly through defense credits. As scale economies are lower in arms production than in civilian production, GaAs integrated circuits had, for a while, a truly higher cost than silicon ones. For decades this cost gap has slowed the development of GaAs electronics. This technology appeared as a "purely" defense technology until the end of the 1980s, without any civilian interest since it was used only in applications for which silicon is truly unable to fit requested needs: space, defense, supercomputers (most notably Cray). GaAs was limited ten years ago to few applications, where it seemed to be unavoidable.

GaAs is not a substitute or a successor to silicon, but its physical and chemical qualities correspond with applications for which silicon is inadequate. Although GaAs integrated circuits are more expensive to produce than silicon ones, GaAs can be used in very high frequencies; it gives a good resistance to heat constraints; it necessitates less energy than silicon integrated circuits; and its utilization limits parasitic impedances (Brodsky, 1990). All these qualities correspond to military requirements and this explains why GaAs is omnipresent in weapons systems. This trend was reinforced by the fact that militaries gave priority to technological performances, not to cost reduction.

If research on GaAs started in the 1960s (following Heinrich Welker's works at Siemens Labs), no major civilian application comes through before the 1980s. As Gummett and Bate (1988) observe about the United Kingdom, "work began in 1966 on GaAs [...] in contrast, no serious commitment to work gallium arsenide was made by the Department of Trade and Industry until 1986" (pp.284-85). Even in the beginning of the 1990s, most observers thought

[1] "The standard merchant chip makers (e.g., Intel, Fairchild Semiconductor, Advanced Micro Devices), which tend to concentrate almost exclusively on short-term development activities, have no onsite efforts in materials other than silicon." (GAO, 1986, p.14)

that GaAs had no commercial future. It then seemed that this technology was in a stalemate (Spaak, 1994).

Nevertheless GaAs products are nowadays everywhere. Mobile phones are based on this semiconductor as well as many items in automobile electronics (especially millimeter radar that prevents car collision). By the end of 1980s some small high-tech enterprises, especially in the USA, France and UK, developed new applications for GaAs. "Traditional" producers, i.e. essentially arms-producing firms, started to diversify their products towards commercial markets. Merchant chipmakers have quickly discovered the commercial potentials of GaAs integrated circuits too. As Barroux (1997) remarks, "a long time treated scornfully by semiconductor professionals–all adepts of its great rival, silicon–gallium arsenide ends nevertheless by gaining its letters patent of nobility in becoming an unavoidable element in mobile phones and reception antennas for satellite transmission" (p.96).

How can we explain such a fundamental change? The main explanation is the incredible development of information technology in commercial markets. Indeed the technological revolution which has begun in the late 1980s (mobile phones, satellites networks), boosted by deregulation policies, opens new perspectives for technologies like GaAs, once considered as pure military technologies. More and more civilian items have to reach performances, which were once only required by the military: "there is some evidence that DARPA's interest in GaAs ICs may have helped to convince research organizations such as AT&T Bell Laboratories that the field deserves an intensive effort"[1] (GAO, 1986, p.5).

What appeared a decade ago as useless and costly performances represents nowadays the basic requirement: fast and large data transfers, high processing speed, with an energy consumption as small as possible to allow satellite or radio transmissions. GaAs-based systems help reducing both cost and use constraints in many of these activities. For instance, using GaAs in satellite data transfer permits to reduce antenna size from 200 to 45 centimeters and its price from FF30,000 to FF600 ($4,900 to $100). Substituting gallium arsenide to silicon allows a substantial reduction of mobile phone size as well as a better reception and a longer autonomy.

As Brodsky (1990) explains, "in an economy and society that depend on the rapid exchange of information as well as on the processing of it, many silicon dominated processors will require a considerable admixture of GaAs components in order to do theirs jobs" (p.56). The strong demand for communication tools explains why GaAs semiconductor is a "hot" market. Moreover the development of demand engenders scope and scale economies that military demand never permitted. The subsequent reduction of cost accentuates the demand and enlarges GaAs markets: unitary price decreases by 20% each time production grows tenfold. Some projections estimate that commercial demand will grow by 30-40% between 1997 and 2002. Non-captive markets[2] represented FF1 billion in 1992, or $160 m., and FF5 billion in 1996, or $800 m. (Vernay, 1998). Captive and non-captive markets are expected to reach FF20 billion in 2000 ($1,600 m.).

[1] The Defense Advanced Research Projects Agency, or DARPA, has been created in 1958 by the US Department of Defense. During certain periods, it was also called ARPA.

[2] Captive markets are formed by the internal production of firms, for their own use. On the opposite, non-captive markets include the production, which is traded.

3.2 *Computer science: development of advanced tools*

Defense R&D has played a leading role in the emergence of computer science. Mowery (1996) shows that in the United States, defense credits helped creating many computer science departments in American universities, in the 1950s and 1960s, and forming the first generations of computer scientists and engineers. Defense projects contributed to the creation of an infrastructure for the support of R&D, training, and technology development that provided important spin-offs to commercial software industry. However this influence has faded away, as commercial firms were increasing their support during the 1960s and 1970s. Thus, industrial and commercial applications have determined the evolution of software industry. In that field, services' influence has quickly reduced, for technological standards were engendered and developed by commercial firms.

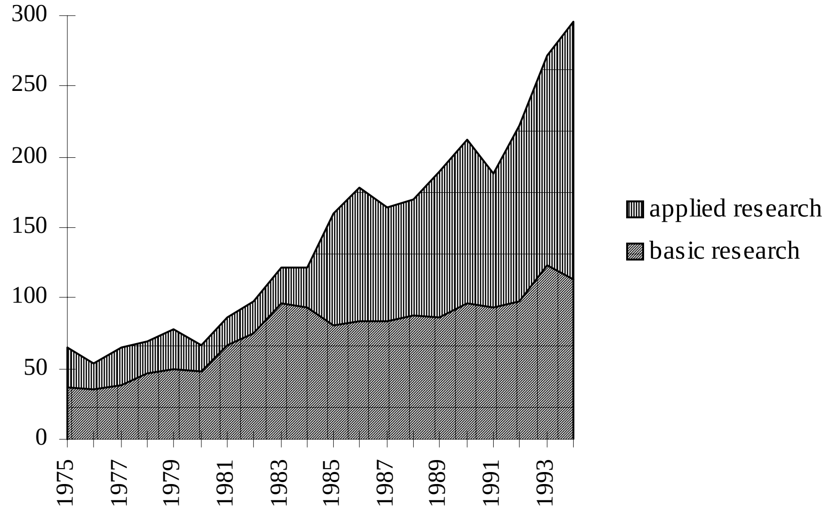
Actually, military software is far from unified: each firm has developed a custom proprietary language, so that programs used by various weapons systems are not compatible. "Defense procurement demand throughout the postwar period has been dominated by highly specialized custom and embedded software, underline Mowery and Langlois (1996), and the products developed for this market found fewer civil applications." (p.958) The dominance of custom applications (at least before the 1980s) reduced incentives to create generic tools or languages.[1]

Even if most software developments in arms production were locked in to proprietary, non-sharable language (and therefore could not favor the development of computer science), this is only a part of services' influence on this technology. Indeed defense agencies also finance emerging technologies that can engender huge return to the whole software industry. The leading role of DARPA in the United States illustrates this trend. While industry and services faced compatibility issues in arms production, DARPA sustained basic research, which contributed a number of important innovations in software and computer architecture, artificial intelligence, etc. The following chart puts into relief the ever-renewed interest of defense agencies for basic research in computer science. In other countries, some defense-related agencies have played a similar role. In France for instance, military needs permitted a support to computer science, mainly through two research centers: LETI and INRIA.[2]

[1] Many ministry of defense tried to define a common programming standard in order to resolve such a problem. The most famous is the Ada language, invented in the 1970s, which was expected to become the unique language of American weapons systems. This project did not reach the expected outcome, and remain marginal as a language compared to COBOL or C++.

[2] The Laboratoire d'Électronique, de Technologie et d'Instrumentation, or LETI, is a research unit of the French Department of Atomic Energy (Commissariat à l'Énergie Atomique). The Institut National de Recherche en Informatique et en Automatique, or INRIA, is a research center in computer science and automation, which has been created in 1967 in order to implement a French national program in such fields (called "Plan Calcul"), with a strong influence from military demands at this time.

Chart 1 – US Department of Defense credits for academic research in mathematics and computer science



Source: National Science Foundation, *Federal Funds for Research and Development Detailed Historical Tables: Fiscal Years 1956-1994*, 1994.

As military software has often a high degree of complexity and request a zero-default rate, defense needs played a central role in the development of software engineering. Many CASE (computer-aided software engineering) tools were developed thanks to military projects. These tools not only increase productivity, but also reduce development costs and the number of errors in software creation (Humphrey, 1989). As Mowery and Langlois (1996) put, "during the late 1970s and early 1980s, ARPA also undertook a major initiative to improve software development and maintenance practices" (p.954). It even created a dedicated center: the Software Engineering Institute in 1984, in order to link academic research and defense-related software development.

Defense R&D has played a precursory role in network management too. As computers have evolved from minicomputer to personal computer in the 1970s, military needs incited defense R&D agencies to support research on networking. Services had to manage large flows of data from many computers located in different places. This situation rises two questions: how can we manage these flows? And how can we secure them? The last question is really important, as computer networks constitutes a potential target and their destruction (or disruption) could paralyze a country's defense system. Soldiers have to communicate with each other and communication systems are based on computers; computer networking and communication early appeared as a major challenge.

Defense R&D was directed not only to network software, but also to development of relevant hardware–boosting the development of packet-switching communications over radio frequencies as well as telephone lines. A special concern was put on communication systems. Services have worked in strong cooperation with telecommunications specialists (GTE, AT&T in the United States; Alcatel, Thomson in France; BT, Racal Electronics, GEC in the UK...). As soon as 1965, MIT's Lincoln Laboratory, under a DARPA contract, laid out "some of the basic concepts for a *packet-switched communications network*" (Flamm, 1987, p.59).

What is not often known is that the basic knowledge concerning local area networks (an essential element in cellular phone systems) was acquired in the early 1970s at the University of Hawaii through a DARPA contract. Many academic researches have benefited from defense R&D support for decades, and their results are nowadays widely used by commercial firms (even though they did not want to back them in the past). While defense R&D on information networks and related systems were considered as purely military need in the 1970s and 1980s, such works constitute now a fundamental engine of the information technology-based economic growth.

The best example of such a spin-off is unquestionably Internet. In the late 1960s, DARPA funded several projects that eventually engendered the ARPANET, a network linking both military sites and defense-related research centers. During the 1970s and 1980s, services were the main users of this network. Nevertheless they have allowed scientists to access basic and applied research made about it, and finally transferred the network to the National Science Foundation. The ARPANET was the forerunner of the NSFNET, that forms nowadays the infrastructure of Internet. Services contributed to the development of Internet since they supported most basic work, developed protocols for data transfers, and relevant hardware.

Nowadays there are still advanced researches in computer science financed through defense funds. For instance, DARPA recently created a $1.5 million project in order to develop and test a new computer network with a high security level, the "Extranet for Security Professionals".[1] Moreover defense agencies in major arms-producing countries have helped developing secure information systems for a long time. For instance, researchers at the University of New Mexico have created truly innovative systems of computer protection, based on immune systems, thanks to defense R&D credits (see Somayaji, Hofmeyr and Forrest, 1997).

As security concerns have raised in the 1990s with the "Internet boom" and other computer networks, such researches have become very useful for civilian activities, and some commercial firms have produced protection systems on these emerging technologies. The commercial success of the Israel-based Checkpoint illustrates the long-term spin-off of defense funding to basic and applied research in computer science. Three computer scientists, who had benefited from military training in computer science and network security, created this firm providing integrated enterprise network security solutions. Once back in civilian life, they developed firewall systems which meet a strong and quick commercial success. Checkpoint revenues boomed in few years. While founded in July 1993, this firm became profitable as soon as the third quarter of 1994. Its turnover jumped from $35 m. to $142 m. (+310%) between 1996 and 1998, while its net income rose from $15 m. to $70m (+360%).[2]

4. Long-term social return to defense R&D

GPS, GaAs and computer science are three examples contradicting the idea that defense R&D has no longer civilian spin-offs. Those who make only a global analysis about defense R&D miss the point, as the situation is quite complex. It is not possible to make a general statement without overestimating some aspects while minimizing others. There are some technological fields where defense R&D may generate useful results in civilian activities, even though services' requirements lead to concentrate the greater part of research effort on development.

Such a misunderstanding results from a focus to short-term impacts of defense R&D. If we take a long-term perspective, it appears that its impacts are neither linear, nor as negative as expected. It is important to precise that defense R&D *may* generate spin-offs and *does not*

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[1] DARPA Seeks Funds for Ultrasecure Computer Network, *Defense News*, 13(3), January 19, 1998.
[2] Checkpoint annual report 1998, pp.2 and 15.

compulsorily generate them: military technology might offer potential applications, but there is no guarantee that such potentialities become effective.

4.1 *A non-linear evolution of technology transfers*

A common perception of technology represents its evolution thanks to a life-cycle model. Such a model is most of time used in order to criticize defense R&D. One considers that services concentrate their research effort on the latest phases of technology's life cycle, so that we cannot expect any social return to this investment. What can be said?

In the early phase of a technology's life, ignorance about it is assumed to be high. Here there are basic discoveries, setting the starting point for many activities (military and civilian, as this kind of distinction is not relevant at this stage). In order for this technology to become useful, services and commercial firms aim at reducing this ignorance–and both define criteria that correspond with their own targets. Even though most of elements are shared in the first stages of technology development, the specific orientation of each activity gives a particular direction to its research. As technologies improve and accumulation of knowledge increases, military and civilian interests tend to diverge as the uses of each domain become more and more specialized.

The technological needs of both sectors have to be better defined (in order to give birth to the required goods), so that the degree to which there are elements of the technology shared by both will decline. As services are supposed to concentrate their efforts on development phases, inevitably it is assumed that defense standards will differ from civilian ones. This increasing incompatibility between arms production and civilian activities explains why defense R&D induces less and less civilian spin-offs. This means that defense R&D devoted to mature technologies is of limited value to the civilian sector then, and eventually becomes a useless burden (absorbing citizens' taxes and inducing an eviction effect on other government-funded R&D).

It is exactly how the relationship between arms production and information technology has evolved, say the opponents of defense R&D. What happened in the 1950s and 1960s in information technology was presented as an exception. Little by little services abandoned their support to basic and applied research; they have increasingly concentrated their R&D effort on the development of well-known technologies. Many studies–from Chesnais to Vaÿrynen–insist on one fact: the leading role of defense R&D in information technology during its first years constitutes the exception that proves the rule. Services cannot have a "good" influence on R&D, and the paths they choose reduce technologies' potential.

The life-cycle theory is useful to understand any technological trajectory, but it is often misused by defense R&D critics. Of course, most of defense R&D focuses on development process, for services' first target is to get the tools they need. However understanding the long-term, macroeconomic impact of defense R&D requires making a distinction between the global affection of defense R&D and qualitative improvements it allows.

The common analysis is that defense R&D is socially useless, for either it supports mature technologies (from which we cannot expect many major improvements), or it backs emerging technologies which do not have large applications and therefore social value. However this is a caricatured representation of defense R&D. In mature technologies, advanced research induced by defense needs can eventually become useful in civilian activities the day when these activities have to upgrade the products. However there is a main way by which defense R&D contributes to economic growth.

Most of time it is considered that services support alternative technologies with limited applications. This opinion is based on the following idea: it is more useful to give credits to "mainstream technologies", i.e. widely-used technologies that attract both R&D and investment, in order to sustain the international competitiveness of a country. It is quite a short-term oriented perception. Obviously social return to R&D is greater if we invest in technological improvements. Such a choice increases firms' competitiveness and a country's growth. Nevertheless no technology has an unlimited potential. In a long-term perspective, it also important to set the seeds of future growth, and not only to take care of existing plants (section 1).

If firms have a spontaneous tendency to focus on incremental innovations within a technological field, States have to make sure that the economy is engaged in a long-term path of growth by multiplying the explored fields. Social return to government-funded R&D can only be assessed in this perspective (section 2). Therefore impacts of defense R&D are not perceptible immediately; they have to be evaluated in length–especially when concerning emerging or radically new fields of research. When R&D is performed by commercial firms, exploration is concentrated on technological varieties most likely to provide a quick and huge return to investors. As Cowan and Foray (1995) argue, "the variety that provides the largest expected net benefit to its adopters will be examined first" (p.861).

The same is not true of defense R&D. When research is performed with a military end in mind, the explored varieties are those most likely to turn out to be technically superior to possible alternatives. This is why services are interested in exploring not only "mainstream" technologies, but also emerging or marginal technologies. Defense R&D permits a real diversity in research that commercial firms cannot afford. Such diversity can reveal its benefits only in a long-term perspective.

4.2 *Strategic requirements and R&D effort*

At the same time services favor traditional weapon systems, they focus also on emerging technologies that can reveal strategic opportunities and make a qualitative difference–strategically speaking. Even though such technologies receive little institutional support and a very small part of R&D credits, their long-term impacts (both military and civilian) are often important. Defense R&D has the potential to play an essential role by encouraging experimentation and diversity in research, especially concerning emerging or new technologies.

By their nature, science and technological opportunities are unpredictable. In order to face such an uncertainty, the military has to prevent any technological surprise by keeping an eye on several researches. Saunders *et alii* (1995) explain that it is imperative to prevent "technological surprises", which threaten to jeopardize national security. Services are extremely risk-averse, in the sense that the "price" of failure to find the best technology (technically speaking, of course) can appear very high. Research, by definition, is risky, and in order to maintain technological superiority services must fund basic and applied research in areas of high potential technologies. Never mind if such investments can succeed (especially in economic outcomes), since failure is one of the desirable features of advanced R&D. If there are not some failures, the technologies might not be pushed far enough and all its military potentialities explored.

One wonders if the numerous projects financed by military funds but not directly oriented to military ends constitute a waste of money. It can be interpreted like this, but it also represents an investment. Financing emerging technologies or advanced research gives services access tomorrow's technologies. The defense support to emerging or radically new research aims at ensuring that States would maintain technological superiority and prevent technological surprises. In information technology, defense research agencies in the major industrial countries have played–and still play–a leading role: DARPA in the United States, CEA (especially LETI in its Advanced Technologies Direction) and INRIA in France, or the Defence Research Agency in the UK (especially one of its four centers, the Royal Signals and Radar Establishment). Table 5 reveals that defense agencies still hold an interest in basic research–even if this kind of research does not represent a large share of defense R&D credits.

Table 5 – Academic R&D funded by the US Department of Defense (1992 constant dollars)

millions of dollars	mathematics*	engineering	sciences of life
1975-1979	331	815	295
1980-1984	492	1,106	406
1985-1989	863	1,552	588
1990-1994	1,892	3,089	1,103
millions of dollars	medicine	physics	environment**
1975-1979	238	420	451
1980-1984	250	517	459
1985-1989	328	557	532
1990-1994	530	1,064	1,007

* computer science included; ** geology, meteorology, oceanography, etc.

Source: NSF, *Federal Funds for Research and Development Detailed Historical Tables: Fiscal Years 1956-1994*, 1994.

As exploring alternative technologies, defense R&D creates opportunity windows by continuing "experimenting long after a market would have standardized on one technology" (Cowan and Foray, 1995, p.865). The example of silicon *vs*. gallium arsenide illustrates such a difference. Once silicon was selected between all semiconductor materials, commercial firms do not even think to invest in any other semiconductor material. Learning effects and knowledge accumulation that have reduced costs and increased performances of silicon-based products reinforced this choice. Defense R&D in new technologies eventually makes these technologies affordable by moving them along learning curves, lowering the costs for later civilian adopters.

Experimentation performed thanks to defense R&D in alternative or emerging technologies can provide a way of exit from technological lock-in that civilian R&D can face, as we have previously seen (section 3). Defense R&D has a complementary action toward commercial firms, as it can provide what market mechanisms fail to engender. When the military supports more than one technology in the development phase, it increases the choice of civilian users, especially in the case of new, complex and/or expensive technologies.

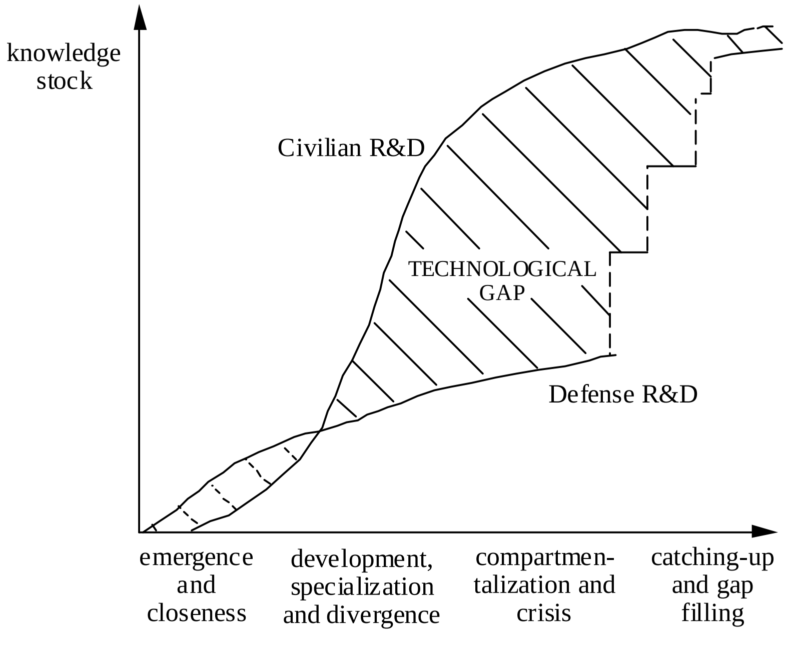
4.3 *Long-term relationship between defense and civilian R&D*

Technologies are not *a priori* either military or civilian (or both). Their character depends on the motivation in which they are developed or employed (Smit, 1991). In a way defense R&D and commercial markets have a reciprocal and complementary action. As commercial firms are short-term oriented, they neglect researches that do not offer quick returns or imply long-term investment. As services are not subjected to this constraint (defense has a truly infinite horizon), they can invest in emerging or radically new research; but they are not able to reveal all their potentialities, since it is not services' basic aim. However this scientific and technological potential can be employed in order to develop commercial products, and civilian firms are the best structures to discover, exploit and concretize such a potential.

As summarized in Chart 2, the ambiguity about economic impacts of defense R&D can be explained by the interaction between, on the one hand, defense R&D and technologies and, on the other hand, defense and civilian R&D. In emerging technologies military research often takes a lead in the first periods of a technology's development, for commercial firms do not want to make such a risky bet. Actually defense R&D is very useful to commercial firms, since its quest of ever-better weapons systems incites the military to finance several (alternative or complementary) projects at the same time. By this defense R&D maintains basic and applied research in fields that have been locked out by commercial firms. As Cowan and Mowery (1995) emphasize, "by continued experimentation, the military can allow laggard technologies to leapfrog leading technologies" (p.865). Compared to commercial firms, the military is less prone to be locked into a unique technology by financial concerns.

First developments of cutting-edge technologies are often, if not always, far from cheap. They need not only heavy investments, but productivity is also very low–and price almost unbearable! The first products based on emerging technologies are most of time so expensive that producers cannot find any commercial outlet (or only in "niche markets"). However the price constraint does not prevent services from using a forerunner technology; arms production may constitute a "testing ground" for such technologies. For instance, military needs permit a substantial decrease in the price of gallium arsenide chips.[1]

Chart 2 – Relationship between defense and civilian R&D



Defense R&D allows exploratory work that establishes a knowledge base, produces learning effects and engenders standards, so that commercial firms find the entry costs into these technologies acceptable. It is remarkable that such a precursory role of defense R&D does not occur only in information technology or in recent decades. Smith (1985), Gummett and Reppy (1998), Bellais (1999) and others show many examples of similar processes in the

[1] The US Department of Defense created a support program in the beginning of 1990s, which resulted in a 40-percent reduction of wafer price between 1993 and 1997, thanks to public orders, investment and research credits (DoD Effort Lifts Gallium Arsenide Production Base, *Defense News*, 12(18), May 4, 1998).

history: industrial standardization, container systems, machine tool-based production, etc. The "demonstration effect" of defense R&D and arms production is noticeable.

However the services quickly limit their effort on specific applications, which correspond with their first missions. On the opposite, once the technology's viability has been revealed, commercial firms then develop numerous applications. In other words defense R&D engenders a *technology-push effect* that is completed by a *demand-pull effect*: firms detect market opportunities (or potentialities) and invest in new technologies in order to offer new products and services. Since the services focus their research effort on a narrow number of specialized applications, arms production ends in technological stalemates and is outdistanced by civilian technologies. This trend results from the (relative) isolation of arms production and defense R&D. Civilian research benefits from a greater interaction between a greater number of actors and competition leads commercial firms to explore a larger number of technological options *within* a given technology.

In the late stage, the technological flow reverses: the technological capability of arms-producing firms and defense research centers can only be upgraded by incorporating outcomes of civilian R&D. There is a "re-convergence" between defense and civilian R&D, by which arms production catches up its relative technological backwardness. Such a theoretical frame can explain why sometimes defense R&D appears to lead scientific and technological progress, and at other moments its seems to lag behind civilian R&D. It is then imperative to place the defense R&D analysis in a long-term perspective.

For instance, CEA in France created in the end of the 1970s to major research programs in microelectronics;[1] and LETI Director, Denis Randet, explains that "nowadays, twenty and fifteen years later, these subjects look as two truly beautiful examples of 'spin-offs'" (Randet, 1998, p.51). Benefits from defense R&D cannot be expected immediately, so that econometrics analyses are quite difficult to implement (particularly since the links between R&D expenditures and economic growth are mostly indirect). By its missions and its means defense R&D creates a technology potential that can become a source of growth. However such a technology transfer requests preliminary conditions:

- the compatibility between defense and civilian technologies;[2]
- the need for firms to find new investment opportunities (and consequently explore and exploit the technological potential engendered by defense R&D);
- the existence of a potential demand from commercial markets;
- a combination between technological and commercial knowledge.

The instance of gallium arsenide offers a good illustration of the clear difference between a technology potential and the effective development of commercial products. As we have seen, gallium arsenide products show a strong growth in the 1990s, leading to several applications. However it is not the first time firms try to exploit its potentialities. In the late 1960s the British firm GEC, a major producer of gallium arsenide, tried to develop commercial products without success. We can explain this failure essentially by two facts: first, nobody expected huge markets for communication tools by this time (excepted in small niche markets); second, few people perceived the possible applications of an alternative semiconductor, because

[1] In 1978, CEA created a research unit dedicated to infrared imagery (aimed at developing specific electronic components). It was followed, in 1982, by a research program on hardened integrated circuits that leads to improving silicon technology, particularly about insulating material (Randet, 1998).

[2] Bertrand Gille explained that technological progress is useful only if it takes place in a coherent technical system. Thus defense R&D can have a positive impact on civilian activities when the technological improvements it allows correspond with what commercial firms or markets request.

silicon applications seemed then almost unlimited. Today perception of GaAs potentialities is quite different, and this is why such a technology attracts now many firms and investors.

Moreover arms-producing firms appear not to be able to exploit alone the technological potential resulting from defense R&D. The success of technology transfer is often based on a cooperation between these enterprises (or defense research centers) and commercial firms. A recent example in automobile electronics can illustrate such a process of cooperative development of technological potential.

DARPA launched several years ago the MIMIC program (millimeter microwave integrated circuit) in order to supply the services with an advanced radar power supply. Development of automobile electronics in the 1990s created a potential market for MIMICs. Such equipment can be useful to prevent car collision. Because of the demand for high volume in the civilian world, Hughes–a defense MIMIC supplier–concluded an alliance with Delco, a world leader in automobile electronics; they redesigned together the production process and drove the costs down from $8,000 to $200 (Gansler, 1995, p.89). The combination of Hughes knowledge and Delco commercial know-how permitted to make gallium arsenide components affordable for civilian applications.

5. Conclusion

The aim of this paper is not to defend defense R&D against the numerous criticisms it gave rise and still gives rise. Many of them are rather justified. Its true objective is to throw into relief the ambiguous role of defense R&D (and more generally arms production) in the dynamics of the economic system. It is not contested that the majority of defense R&D can be considered as a waste in a macroeconomic point of view, since it does not contribute to the economic growth. Actually it is not nonsense: defense R&D aims first and over all at engendering new weapons systems, not at sustaining economic growth. It is primarily by this means that it is justifiable and justified.[1] However staying at this level of analysis misleads our comprehension. Pure military works take the larger part of the cake, but you cannot see the wood for the trees.

A quantitative relationship between defense R&D credits and economic growth misleads the analysis, since the qualitative impact of a small part of these expenditures is without proportion with the public investment it represents. As financial and institutional investors place an ever greater emphasis on short-term returns (the well-known quarterly earnings), there is a clear shift toward cuts in civilian-sponsored R&D. The remaining effort concentrates on well-known technologies, because they offer the bigger and more expectable return to investors. Escaping from profit constraint, defense R&D can support marginal or emerging technologies, and opens new fields of research. In that way the military indirectly contributes to the scientific and technical progress. If these researches do not present clear perspective nowadays and often appear as scientists' utopias, they sometimes reveal huge opportunities of investment and growth in a long-term perspective.

Nowadays, one decade after the end of Cold War, defense R&D seems to keep its leading role towards emerging or radically new technologies. When analyzing basic and applied research which are supported by defense research agencies in the main arms-producing countries, it appears that tomorrow's technologies can still attract services' interest–like biomimetics, nanosciences, intelligent structures, optoelectronics, artificial intelligence,

[1] In many countries, and especially the United States, defense agencies have been criticized when they engaged in R&D projects which were wider than their essential missions.

advanced communication systems, etc. Even more basic research receives a greater and greater part of defense R&D: basic and applied research represented about 3,4% of total R&D credits between 1987 and 1992 in the United States, and its absorbs more than 11% in recent years (Cohen, 1997). Thus this budgetary post is expected to rise after 2000 in most countries.

This original research direction is important. Even if civilian (and commercial) R&D seems to lead the scientific and technical progress today, a closer look shows that most works produce only incremental improvements to existing technologies. For instance, electronics shows an impression of ultrafast change. Products certainly evolve at an incredible rhythm (Moore's Law about microchips), but fundamental technical innovations take as much time as in other activities: "A ten-year delay between first demonstration and a concrete industrial production is not very exceptional." (Randet, 1998, p.52) Such a long-term investment is far from commercial firms' target. Defense R&D can thus play a leading role by supporting emerging and radically new technologies that can reveal their economic potential in about ten or twenty years. Defense research appears to stay a driving force of information technology now and in the next decades.

The real stake is not to reduce defense R&D in order to increase civilian research, but rather to focus it on basic and applied research in order that services can always access to the most advanced technologies (and therefore help, indirectly, commercial firms and boost economic growth). As Libicki (1995) puts it, "the notion that more plowshares can be gotten only by beating swords overlooks how advances in sword technology may enhance plowshare technology" (p.54). Defense R&D may represent an economic burden in a short-term and budgetary perception. However, replaced in a longer perspective, its usefulness appears more clearly. The question is then: how can its technological potential be revealed (economically speaking)? The interaction between military and civilian technologies depends not of their own characters (military, civilian, or both), but essentially of economic actors' choices and behaviors.

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