Defense innovation at any (out of control) cost? The stalemate of today's R&D policy and an alternative model

Renaud Bellais

Technological superiority is considered to be a key element to achieve defense effectiveness, and R&D plays a major role in accessing relevant leading-edge technologies. This is the reason why since World War II the United States and Western European countries have been pouring a large share of their R&D expenditures into applications for defense. However, defense R&D has become increasingly expensive while being less and less able to generate disruptive technologies. In the large arms-producing countries, spiraling R&D spending amplifies its economic burden and crowds out civilian R&D. More efficiently conducted defense R&D thus could assist civilian R&D budgets as well.

As the biggest military spender, the United States most experiences the limits of the existing model of defense R&D. In spite of doubling its budget from 2000 to 2008, with outlays growing from $37.6 billion to $74.4 billion, the Pentagon is experiencing technology shortcomings and failures. For instance, spending for developing counter-IED systems seems out of control yet with little to show for it. One may therefore wonder whether current R&D policies can achieve their goals or whether it should be transformed.

Military spending trends show that a defense technology race remains at the heart of defense procurement in the occidental world. Even though non-western countries such as Russia, India, or China have been increasing their defense R&D, they have not reached levels equivalent to the biggest NATO spenders. One must wonder how to stop the upward drift of defense R&D spending while improving its effectiveness, that is, nurturing leading-edge technologies at an affordable cost.

This article is divided into two sections. The first emphasizes the contradiction between the quest for technological superiority as the driver of defense R&D spending and the shortcomings of the dominant approach. It underlines the weight of the follow-on principle to explain spiraling R&D costs. The second section identifies the limits of the Lead System Integrator model. Relying on the innovation literature, the article proposes venture capital mechanisms as a possible alternative to both reduce the burden of defense R&D and to improve its effectiveness.

Technology races as the engine of defense procurement

Because it is considered a means to counter existing or emerging threats and because of the rising costs of defense technologies, the armies of the main arms-producing countries have been investing heavily in R&D, even after the end of the Cold War. Nevertheless, today's R&D model, set up during the Cold War, appears less and less adapted to deliver defense innovation at a sustainable cost.

Table 1: Weight of R&D in equipment spending (2006, millions of euros)

	Procurement	*R&D*	*Equipment*	*R&D share*
United States	83.0	58.0	141.0	41.1%
European Union	29.1	9.7	38.8	25.0%
United Kingdom	7.5	4.0	11.5	34.8%
France	6.3	3.8	10.1	37.4%
Germany	3.7	1.0	4.7	21.9%

Sources: European Defence Agency; European-United States defense expenditure in 2006; and 2006 National Breakdowns of European Defense Expenditure, Brussels, 21 December 2007.

Military threats and technological superiority

Since the 1940s, armed forces have fielded advanced technology through an aggressive pursuit of R&D and the development of a high-tech defense industrial base of unprecedented scale.[1] R&D represents between one-fifth and two-fifths of the equipment spending of large NATO countries (Table 1).

Once driven by the East-West arms race, technological superiority remains today at the heart of defense procurement. The prominent defense analyst Jacques Gansler writes that "although we no longer face the threat posed by a global peer competitor like the former Soviet Union, we still live in a very dangerous world. It is a world marked by uncertainty and unpredictability; a world in which multiple possible aggressors pose a wide range of potential threats and hostile actions."[2] This appraisal seems to be shared by the leading arms-producing countries.

Since the 1990s the threats have become dramatically more heterogeneous.[3] NATO countries consider advanced technology as an appropriate and adequate answer: "Potential opponents will also have access to much state-of-the-art technology, since they can purchase it on the open global market. Thus DOD must 'run faster' than others, rapidly feeding on the global base rather than relying almost exclusively on its own sponsored R&D as it did during the Cold War."[4]

Western armed forces feel that strategic surprises can be avoided by mastering innovation and disruptive technology. This explains why defense R&D remains a key dimension of defense spending. Even though technology is not the unique answer or

Table 2: Defense R&D in constant 2006 euros (millions)

	*1994**	*2006*
United States	37,200	58,000
France	4,730	3,777
United Kingdom	3,830	4,012
Germany	1,240	1,035
Italy	530	252
Sweden	360	267
Spain	270	201
European Union 26	11,500	9,700

* Available data between 1993 and 1995, 1994 being the most common year.
Sources: SIPRI Yearbook 1996, Oxford University Press, 1996, p. 381; European Defence Agency, 2006 National breakdowns of European Defence Expenditure, Brussels, November 2007; Office of the Undersecretary of Defense (Comptroller), National Defense Budget Estimates for FY2008, U.S. Department of Defense, March 2007; and author's calculations.

effective by itself, it is perceived as crucial to analyze threats and to maintain military dominance. This is the reason why merely sustaining the technological effort is not considered an option but a necessity to counter unexpected — and sometimes unpredictable — foes.

This view also explains why the United States and Europe still spend almost €70 billion a year in defense R&D. This represents a huge economic burden, and one whose legitimacy can be questioned. But maintaining technological superiority requires an effective technology policy both in terms of operational and budgetary impacts. This raises two major questions. First, are defense R&D budgets compatible with the required level of investment? Even if some countries are able to fund multiple projects (many of them in advanced technologies), none of them is rich enough to cover the whole range of potential technologies or innovations. Do defense R&D spending trends lead to an unsustainable burden? Second, is defense R&D policy effective? As the current model is not always able to produce the expected results, especially to identify and/or take advantage of emerging technologies, can an alternative model improve the effectiveness of R&D spending?

Budgetary pressures on R&D spending

In spite of technology-driven defense, R&D spending paid the price of both the end of the Cold War and strong downward pressures on public spending in the 1990s in the United States and in European countries. Cutting R&D helped preserve operational capabilities, and this choice was the easiest since it was almost without perceptible effects in the short term.[5] A bit more than a decade later, R&D spending has recovered (Table 2). The United States has steadily increased its defense R&D

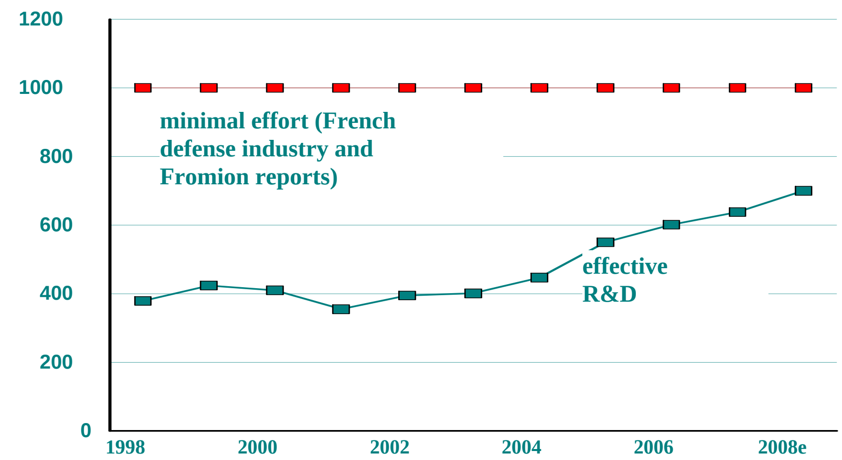

Figure 1: French R&D expenditure
Source: Directorate of Financial Affairs, French Ministry of Defense

since 2002, reaching its highest level ever. In Europe, defense R&D has increased in recent years but remains lower in real terms than in the early 1990s. This is explained, relative to the United States, by stronger budget constraints and a lower priority given to defense.

Even though defense R&D has reached an historical peak within NATO, it is insufficient to keep pace with the long-term evolution of defense R&D costs that since the 1970s have increased in real terms at a rate of 4 percent per annum.[6] Even for the Pentagon, a 63 percent budget increase in real terms from 1995 to 2008 is not sufficient to compensate for the doubling of R&D costs. The scissors effect is more important for European countries. Almost stagnant resources are, in real terms, no longer sufficient to keep pace with technology costs. For instance, despite an upward trend of its R&D effort since 2002, French minimum expenditures are still below those needed as defined by both the French defense industry association and the Fromion Report (Figure 1.[7]

Due to spiraling costs a structural gap exists between available budgets and the requested level of investment. NATO countries seem unable to sustain the technology intensiveness of defense systems. There is limited room for additional resources in France and the United Kingdom, and even in the United States projections anticipate a fall of R&D spending from $79.6 billion in 2009 to $63.4 billion in 2013 (in real terms).[8] One may therefore question whether simply to keep increasing R&D spending is the proper way ahead. Instead, one should analyze the causes of spiraling costs.

The effectiveness of defense R&D results from both the spending level in a given technology and how such spending is managed. In fact, threshold effects result from the evolution of defense-related technologies. In particular, one cannot expect a linear relationship between R&D spending and its output: below a certain level of investment in a given technology, the output of R&D falls rapidly. Exploring investments in integrative technologies in a dynamic optimization framework, Setter and Tishler find that under nonlinear, convex development costs it is not optimal to build military forces using a myopic, short-term approach.[9] It is difficult to transform an armed force within just a few years. Consequently, early investment in technological infrastructure is required because the entry cost in technology is high and the transformation period ranges over more than a decade.

If a country's investment in a given technology is too limited, it cannot expect to keep pace with the state of the art, and it is not worth investing in that technology. But even if NATO were to carefully select the technologies in which it invests, this would only cover one part of the story. The more important concern is to understand whether the existing R&D model itself is appropriate to nurture emerging technologies.

Shortcomings of defense R&D

Defense R&D provides a low rate of social return — a lower rate than civilian R&D expenditure in equivalent fields.[10] In addition, it appears that defense projects are increasingly expensive and do not deliver on their promises.

Frank Lichtenberg shows that, holding non-defense R&D constant, defense R&D has essentially no effect on productivity growth. He underlines that "both micro and aggregate estimates of the (social) 'rate of return' to investment in government-funded (largely defense-related) R&D — or its impacts on productivity growth — are insignificantly different from zero, and are much smaller than estimates of the rate of return to privately-funded R&D."[11]

Moreover, the costs of defense R&D rise more quickly than for civilian projects. This results in part from the quest for advanced technology as well as from the obsessive drive to improve existing technologies through incremental innovations, leading to what Mary Kaldor called the Baroque arsenal. As Adelman and Augustine note, "the problem with technological sophistication is that the last 10 percent of performance sought typically adds one-third of the cost and two-thirds of problems."[12] This remains true, as demonstrated by Schinasi's critique of the major defense programs.[13] Incremental innovations are expensive, do not guarantee results, and generate limited civilian spinoffs.

In addition, defense R&D does not always fulfill its objectives: programs are delayed, costs are steadily rising, and it cannot deliver the expected results. If one takes the example of the Pentagon's major programs (Table 3), costs are drifting upward and schedules are delayed. The R&D failures explain why programs seem out of control, since programs are launched before technologies are mature enough to be incorporated. However, there is "not a strong positive association between equipment quality and ... the fraction of defense expenditure applied to R&D."[14]

Table 3: Analysis of DOD major programs

Fiscal Year	*2000*	*2005*	*2007*
Number of programs	75	91	95
Change to total RDT&E costs from first estimate	27%	33%	40%
Change to total acquisition costs from first estimate	6%	18%	26%
Estimated total acquisition cost growth	$42bn	$202bn	$295bn
Average schedule delay in delivering capabilities	16 mths	17 mths	21 mths

Source: Schinasi (2008, p. 5).

The marginal gain resulting from improving a given technology is not always the best way to achieve military dominance. It can be more relevant (operationally and financially) to develop an alternative solution. The focus on existing technology corresponds to what James Kurth has called the follow-on imperative, i.e., the evolution of systems, generation by generation, without questioning the usefulness of in-service platforms at increasing costs for decreasing marginal benefits.[15]

Because they cannot afford failure or delays with limited resources, cash-strapped armed forces favor well-known technologies rather than disruptive or emerging ones. They tend to become more risk averse and prefer limited results to unpredictable technological disruptions with unknown potential. This vicious cycle has two major consequences: defense R&D is bound to have a diminishing rate of return, and armed forces are less able to avoid technological surprises because they invest less and less outside their core technological base.

Keeping pace with emerging technology then begs for an alternative mechanism, one that helps increase the rate of return to defense R&D (and eventually reducing its economic burden) and to keep armed forces aware of technology disruptions and the related potential defense applications.

The need to transform defense R&D policy

Current defense R&D is not capable of providing troops with leading-edge, disruptive technologies. This does not mean that new technology would be perfectly effective; but one can expect a bigger bang for armed forces' buck and, eventually, a reduced defense burden.

Armed forces need to find the proper balance between incremental and disruptive technologies. Improving existing technologies through the Lead System Integrator (LSI) model is useful to some extent but not to avoid technological surprises. In this section, an alternative model, relying on venture capital, is suggested.

Table 4: Research and development in defense R&D (2006, million euros)

	R&D	*R&T*	*R&T share*
United States	58,000	13,600	23.4%
United Kingdom	4,012	733	18.3%
France	3,777	762	20.2%
European Union	9,700	2,500	25.8%

Sources: European Defence Agency; European-United States Defense Expenditure in 2006; and 2006 National Breakdowns of European Defense Expenditure, Brussels, 21 December 2007.

Overcoming the follow-on approach

The armed forces and incumbent firms are quite capable to manage the evolution of known technologies. For instance, the United Kingdom identifies required technological investments through its defense technology strategy. The French government's arms directorate (the DGA) cooperates with industry to elaborate on its thirty-year planning exercise, the "plan prospectif à 30 ans". Improvements can be anticipated and therefore organized through investment plans. But such an organization is ineffective when intending to catch unexpected technological breakthroughs which are more difficult to identify and whose results are highly uncertain.

Therefore a paradoxical trend emerges: the less money armed forces receive, the more they concentrate on D rather than R. Carter notes that "much defense R&D today goes to keep old 'legacy' systems going or to prop up faltering programs, rather than launching new leap-head military systems."[16] A large share of the R&D budget is allocated to existing technologies, even mature ones, explaining why development absorbs at least three-fourth of R&D credits (Table 4).

Some funding for nonconventional research does exist. The French DGA set up a mechanism for "non-solicited proposals." The Pentagon likewise manages an independent R&D program. Supposed to overcome the intrinsic limits of its own R&D organization and to keep industry innovative, it was designed to reimburse the defense industry for a share of its self-funded R&D so that firms were able to explore new technologies.[17]

But such mechanisms provide very limited funding, at least when compared to the overall R&D effort, and they are not as effective as expected. First, allocated credits have decreased over the last two decades (Figure 2) while the entry requirement to many technologies rose steadily. Second, a large share of credits is diverted toward conventional projects, for such mechanisms are used to achieve projects otherwise underfunded or not funded at all, in effect becoming alternative funding for incremental innovation. As Carter notes, "over time the government is tending to dictate more of the programs, making them less truly the results of the independent judgment of non-government scientists and engineers."[18]

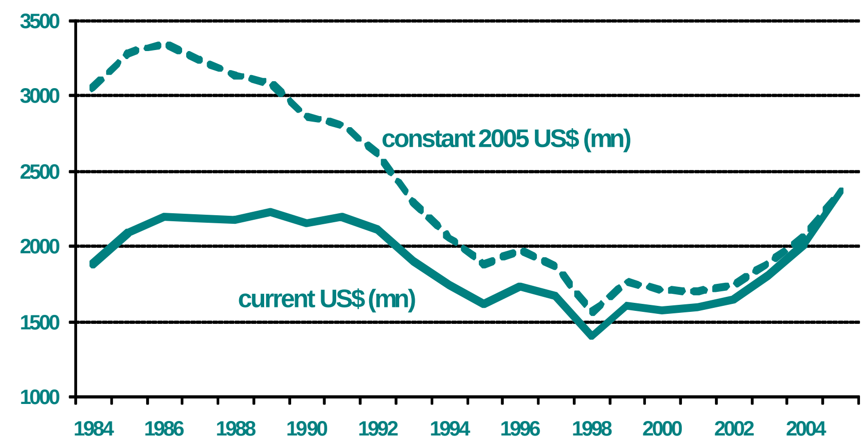

Figure 2: Independent R&D: DoD share of allowable costs
Source: Defense Procurement and Acquisition Policy, DoD, http://www.acq.osd.mil/dpap/policy/cpf/ [accessed 5 October 2007].

Moreover, since the 1990s the defense industry is less favorably disposed to disruptive innovations. The main arms-producing countries gave prime contractors a greater role, promoting a Lead System Integrator (LSI) model in which the prime contractor is the state's unique interlocutor. This channels more R&D funding toward prime contractors and large projects (especially technology demonstrators). Consequently, less money is available for innovative small firms that have limited access to the ministry of defense.

This model favors existing technologies rather than nurturing emerging or disruptive ones. Tratjenberg emphasizes: "The development of big weapon systems in the decades of the Cold War led to a high concentration of both R&D and procurement into a few large corporations, conferring on them a great deal of market and bargaining power. It is quite likely that this had detrimental effects in terms of costs and effectiveness, and it may have steered technical advance into questionable directions."[19]

Developing a growth model, Matsuyama demonstrates that a given economy can have not one but two growth regimes simultaneously: a Solow regime in which growth results from capital accumulation, and a Romer regime in which growth results from knowledge accumulation.[20] He underlines that the market rules differ from one regime to the other because of a far different weight given to innovation.

An audacious parallel could be drawn with regard to defense innovation. A monolithic R&D policy seems irrelevant to nurture simultaneously incremental improvement of existing systems and path-breaking innovations that may dramatically transform defense. This leads the United States to question whether this alternative model for exploratory R&D corresponds to incumbent firms' abilities.

Incumbent firms and disruptive technologies

The follow-on bias is amplified by today's place given to LSIs. If incumbent firms' resistance to change and disruptive technology are widespread in many industrial sectors, this is especially true in defense:

- Incumbent firms are keen on developing incremental changes in technologies that they master (reinforcing their own position within the defense market), but they tend to resist disruptive change when it jeopardizes their technology portfolio (becoming obsolete) or requires additional investment.
- Such conservatism exists symmetrically on the demand side, as armed forces tend to promote technologies they know and for which there exists a usage doctrine. Services tend to resist new technology that requires changes in their missions and organization.

As Gansler writes: "A dialectic conflict is created by technological advancement. On the one hand, technological opportunities that result in incremental changes (…) are rapidly accepted and enthusiastically pushed forward — perhaps too unquestioningly. On the other hand, those technological opportunities that offer revolutionary changes are often outside the paradigm; thus they meet with extreme institutional and structural resistance, with every effort made to reject them."[21]

Even though large firms try to keep pace with disruptive technology, their structural functioning creates intrinsic limits. Large firms need to provide quarterly results which require both large and certain markets. Emerging technologies are the opposite: high risks, uncertain, long-term results, and nonexistent (if not entirely unpredictable) markets. Where to invest is obvious: "A project to commercialize a disruptive technology in a small, emerging market is very unlikely to be considered essential to success in a large company; small markets don't solve the growth problems of big companies."[22]

Large firms must focus on projects for which market demand and profitability are guaranteed or under control. All their organizations favor incremental innovations rather than disruptive technologies. Christensen writes that "expecting achievement-driven employees in a large organization to devote a critical mass of resources, attention, and energy to a disruptive project targeted at a small and poorly defined market is equivalent to flapping one's arms in an effort to fly: it denies an important tendency in the way organizations work."[23]

In commercial markets this dilemma is often overcome through a merger and acquisitions (M&A) strategy. Large firms invest intensively in innovations but mainly to develop or improve their knowledge capital. When they look for disruptive innovation, especially if it threatens their core business, acquiring small innovative firms is the most effective strategy.[24]

But this possibility is quite limited in defense. Absent an alternative market, defense technologies are developed only through R&D or procurement contracts; public contracts then shape the industrial base. In contrast to the civilian sector, when a firm is looking for a technology that she does not have, it is difficult to find an off-the-shelf solution. This creates a difficulty when, as emphasized previously, R&D policy does not create a window of opportunity to fund emerging technologies.

With R&D policy focused on incremental innovations and managed by LSIs, one can expect a gap to arise between the advancement of science and the knowledge mastered within the defense industrial base. If armed forces expect to keep pace with technologies and avoid surprises at an affordable cost, they need an alternative, complementary approach. In this respect, a mechanism based on venture capital, one that combines market incentives and investment strategy, may fill this gap.

Applying venture capital mechanisms

Beyond the intrinsic organizational limits of incumbent, large firms, difficulties to deal with emerging technologies arise for several reasons: technology legacies, sunk investments, the need for short-term financial results, and the influence of existing customers. One solution to overcome such limits is to set up an ad hoc structure dedicated to the development of a given technology. Here it seems of interest to explore the use of venture capital.

Venture capital (VC) is a risk-seeking, project-focused approach possibly compatible with the time horizon for emerging or disruptive technologies. Investors expect no immediate returns so long as they can forward to an attractive medium-term exit. Organized for a given project, VC can gather the critical mass of resources and is not distracted by other issues. On the financial side, risks become acceptable as investors employ a portfolio strategy: even if one project fails, they expect that the average return across all projects compensates for taking higher-than-average risks.

Empirical research underlines that VC-funding has strong positive effects on innovation. Gompers and Lerner state that "on average a dollar of venture capital appears to be three to four times more potent in stimulating patenting that a dollar in traditional corporate R&D ... venture capital, even though it averaged less than 3% of corporate R&D from 1983 to 1992, is responsible for a much greater share — perhaps 10% — of U.S. industrial innovations in this decade."[25] Venture capital can help develop technologies faster and more effectively than large firms.

Even though it is not adapted to manage the whole of defense R&D, developing a defense research and technology (R&T) strategy based on venture capital could help both to identify promising technologies and to nurture their defense applications. Innovative approaches are not terra incognita for the defense world. Beyond the interesting experience led by the U.S. Defense Advanced Research Projects Agency (DARPA) that has supported emerging technologies since the 1950s, other institutions have recently been developing alternative mechanisms to improve the effectiveness of their R&D.[26] For example, the CIA launched its own fund, In-Q-Tel, in 1999; and the U.S. Army in 2003 granted MILCOM Technologies the management of OnPoint Technologies, its VC-structure.[27]

However, venture mechanisms have limits, too. Some of the commercial VC-models are clearly designed as asset-stripping, short-run, profit-maximization vehicles. But the proposal here is not to simply channel defense funding through VC-funds but to exploit their demonstrated advantages for developing alternative means to nurture defense innovations. Defense VC-structures should have specific features corresponding to the expectations of defense. Even though the selection of projects should rely on the basic criteria of venture capital (technological and commercial potential, long-term profitability, expectable exit, and so on), its first objective would be to explore emerging or disruptive technologies and determine their potential for defense applications.

There are few experiences on which one can rely to develop an empirical analysis of the effectiveness of VC-mechanisms for defense objectives. Nevertheless, one can identify three criteria which could contribute to a successful utilization of such mechanisms to improve the social returns of defense R&D. First, a defense fund can be effective if and only if it is able to take risks and avoid limiting its potential losses ex ante. While having severe criteria of selection, it should invest in several projects and expect a big success for one investment in ten as well as an average failure rate of about 50 percent, the regular rate in the VC-industry. This is a prerequisite for truly exploring technologies with possible defense applications, and thus in avoiding technological surprises.

Second, it must avoid mimicking private venture investors. Venture capital is a cyclical industry. Cycles result from the nonlinear emergence of technological opportunities, but also from herding effects, resulting in over and underinvestment phases. A defense fund should not invest in technologies already funded by private investors, avoiding the mistake identified by Gompers and Lerner: "Government programs have frequently been concentrated during the periods when venture capital funds have been most active, and often have targeted the very same sectors that are being aggressively funded by venture investors."[28] The true aim of such a fund is to fill the gap between the advancement of science and technology and the available funding to develop innovations; then supporting risks which are not compatible with a commercial and/or profit-oriented approach. It should also counterbalance rather than exacerbate the cyclical nature of VC-investment, supporting the development of emerging technologies when private investors reduce their commitments.

Third, a defense fund should have a not-for-profit approach: it must look for a "return to technologies," rather than return to investment as In-Q-Tel does. As McCullagh notes, "the true mission of In-Q-Tel (... is) to tap the best minds in the technology sector and spur the development of products the CIA desperately needs and doesn't have the time or expertise to develop itself."[29] The aim of such a fund is to explore the defense potential of technological options so that armed forces have access to state-of-the-art technologies when needed. Forgetting this goal could jeopardize its true mission and lead the fund to behave like any other VC-fund, as underlined in the U.K. by the failure of Defence Technology Enterprise in the field of technology transfers from defense to commercial applications.[30]

Conclusion

As defense R&D faces limits in its current organization, improving its effectiveness and reducing the economic burden of defense spending requires an alternative approach, at least for emerging and disruptive technologies. The view put forward here is aimed at identifying the limits of defense R&D and analyzes its causes. Consequently, it is suggested that incremental innovations, organized through a LSI model, can deal with improvements in existing technologies but is not fully satisfying for unknown technologies.

The logic of venture capital is of interest, as its mechanism corresponds to the specific conditions of such technologies. With limited funding and adequate management rules for a specialized VC-fund, one could expect that armed forces would be more capable of keeping pace with technological change. The aim here is not to develop such an alternative approach but only to underline its intrinsic interest and suggest a research agenda on the possible relationship between defense R&D and the principle of venture capital.

The stakes are not limited to the effectiveness of public spending and access to military dominance. Improving the effectiveness of defense R&D is a good means both to reduce taxpayers' bills and to reallocate R&D funding toward civilian, socially-sound projects. Indeed, even though defense R&D has sometimes been used as a substitute for civilian R&D policy, one cannot consider defense as the best catalyst for R&D. It would be more relevant to invest directly in civilian projects. One could then expect that by improving the utilization of defense R&D, it would be easier to limit its growth and eventually push armed forces to rely on civilian R&D rather than supporting a specific agenda.

Notes

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1. Technology change is the engine of defense procurement since the Renaissance, but it is only after World War II that the alliance between armed forces and science became effective. Thereafter, defense R&D became really significant as underlined by the works of Charles Wright Mills, Seymour Melman, or Claude Serfati (Bellais,

1999).

2. Gansler (1998, p. 1).

3. See, for instance, Bellais and Le Blanc (2002) on asymmetrical threats or Tratjenberg (2006) on terrorism.

4. Carter (2001, p. 131).

5. Middleton, *et al*. (2006) demonstrate that there is a relationship between defense R&D and equipment quality about 10 to 25 years later. Reciprocally, impacts of budget cuts appear only about a decade later.

6. Hartley, *et al*. (2008).

7. CIDEF, L'industrie de défense française: Une dynamique à soutenir, des enjeux européens, Paris, 2004. Yves Fromion, MP, Les exportations de défense et de sécurité de la France, Report to the French Prime Minister, Paris, July 2006.

8. OUSDC (2008, p. 76).

9. Setter and Tishler (2006).

10. Bellais (2004).

11. Lichtenberg (1995, p. 456).

12. Adelman and Augustine (1990, p. 142).

13. Schinasi (2008).

14. Middleton, *et al*. (2006, p. 117).

15. See Kurth (1993).

16. Carter (2001, p. 135).

17. “Contractors shall be encouraged to undertake IR&D activities that may further national security in a broad sense, may lead to a superior military capability, or may lower the cost and time required for providing that capability” (DoD, Directive 3204.1, 10 May 1999).

18. Carter (2001, p. 135).

19. Tratjenberg (2006, p. 195).

20. Matsuyama (1999).

21. Gansler (1989, p. 218).

22. Christensen (1997, p. 138).

23. Christensen (1997 p. 139).

24. This is the strategy followed by big R&D spenders such as Cisco, Microsoft, Novartis, and GSK.

25. Gompers and Lerner (2003, p. 19).

26. For a presentation of DARPA’s history, see e.g., Edwards (2005).

27. OnPoint Technologies is a $25 million, not-for-profit, strategic private equity organization aimed at investing in promising power-supply technologies.

28. Gompers and Lerner (2003, p. 24).

29. McCullagh (2000).

30. A technology broker created by financial and investment institutions to exploit MOD’s technology portfolio, DTE failed as it only tried to make profit in a short-term perspective — assuming that once a blueprint, patent, or idea had been located, it could be easily transferable — rather than investing to develop commercial applications of defense-funded applications. For further analysis on the misleading mix between commercial targets and defense issues, see Bellais and Guichard (2006).

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