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Defense firms adapting to major changes in the French R&D funding system

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Abstract

The structural changes inside the French innovation system have impacted the role of defense firms since the late 1980s. Major changes have affected the defense budget and public R&D funding system in particular. The aim of this article is to understand French defense firms' repositioning within the National Innovation System (NIS) based on an analysis of their R&D behavior over a long period of time (1987 to 2010). We show that French defense firms remain major players in the NIS and faced up to these major changes by adapting the funding of their R&D and their research priorities and rolling out new innovation capabilities. Additionally, they developed new innovation models to take advantage of new collaborative partnerships developed for civil and military markets.

JEL classification: G32, O32

Key words: Defense firms, System of innovation, R&D

Introduction

Little research has been conducted on the role of defense firms in national innovation systems (NIS), defined in the broad sense of Lundvall (1992),¹ and their specific features (Mowery 2009). Some exceptions include Mustar and Laredo (2002), Versailles (2005), Belin and Guille (2008a and 2008b), James (2009) and Guillou et al. (2009). However, these firms are major players in the NIS of a number of European countries, although their role has changed considerably over the last three decades (Mérindol and Versailles, 2010; Lazaric et al., 2011). Such great changes have sometimes led to the belief that defense firms have lost their place as technological driving forces, when in fact their role remains significant (Serfati, 2008). The purpose of this article is to understand defense firms' repositioning within the NIS from a French point of view. In particular, companies have changed their R&D financing structures, as well as their innovation

¹ The NIS includes, in the strict sense, "the organisations and the institutions implicated in research and exploration like R&D departments and university technological institutes" and in the broad sense, "the economic structure and the institutional organisation affecting learning as well as research and exploration—the production system, the commercial system and the financial system are presented as subsystems in which learning takes place" (Lundvall, 1992: 12).

capabilities, in order to enhance their combination of internal and external assets (Lazaric and Raybaut 2014; Ayerbe et al., 2014).

Our study is based on an analysis of R&D behavior in French companies (French R&D survey from the Ministry of Higher Education and Research) over a long period of time (from 1987 to 2010), taking into account macroeconomic and mesoeconomic levels. In general, changes within the NIS are only studied from a macroeconomic viewpoint (for some exceptions see Guillou et al. 2009). Our analysis aims to show the interest in a macro-meso approach in order to better understand the changes in defense firms within the NIS since the late 1980s, which were marked by the end of the Cold War and the global shift toward the liberalization and the financialization of the economy. Indeed, Lundvall et al. (2002) focused on two aspects of innovation systems: first, the structure of the systems, i.e., what is produced in the systems and what competences are featured in the system; and second, the institutional set-up, i.e., how production innovation learning and innovation actually occurs in the system. Thus, our background is explicitly framed in a context where financial changes and knowledge economy matter not only at the macro level but also for actors and players within this system (Foray and Lundvall 1996). Using the NIS approaches developed by Lorenz and Lundvall (2006) and by Fagerberg and Srholec (2008), we will analyse how, as the innovation model becomes more open, defense firms boost their skills and develop new capabilities (Hobday et al., 2005; Nielsen et al., 2012; Mérindol and Versailles, 2016). These dynamics, sometimes entirely new, show that these companies are highly capable of adapting their innovation models.

Far from simply enduring the new macroeconomic constraints and defense budget cuts,² particularly in the amounts allocated to defense R&D, as discussed below, companies in this sector mobilize and redeploy their technological skills proactively, in order to remain key players in the NIS. At the same time, they forge new collaborations, conserving and renewing their tangible and intangible assets in today's knowledge economy (Molas-Gallart and Tang, 2005; Mustar and Wright, 2010; Azzam et al., 2016).

Defining and identifying defense firms is a complex matter since the definition of a relevant perimeter is complex and the data are not always available (Dunne, 1995). As this analysis focuses on their R&D behavior, we chose to identify defense firms based on R&D funding received directly from the Defense Ministry. This definition allows us to take into account prime contractors and subcontractors financed by the Defense Ministry, which is used for example by Mowery (2012).

First, we examine how these defense firms have repositioned themselves within the NIS in light of this new context, characterized in particular by a significant reduction in budgets and direct subsidies for firms in this sector. Second, we analyze the ways in which these companies have

² After a decade of increases, the French defense budget, which was approximately 36 billion euros in the early 1990s, declined gradually during the peace dividend period (a steady 2000 euros) to reach less than 30 billion euros in 2002. Despite an increasing trend since 2003, it was only in 2010 that it was equivalent to that of 1981 (32 billion euros).

adapted their R&D and highlight new forms of collaboration and intellectual property rights (IPR) valorization.

1 – Faced with the new NIS context, R&D firms financed by the Defense Ministry still have a significant role

Defense firms have long played a major role in the French NIS. Beginning in the 1950s, defense policy, which focused on achieving strategic and technological autonomy and revolved around large projects using disruptive innovations, relied on large, usually public national defense groups (Mustar and Laredo 2002; Serfati 2001; Laperche et al. 2008). Until the early 1990s, French defense firms still achieved more than half of the business R&D expenditure and received almost all direct public R&D funding (Belin and Guille 2008b). However, since the late 1980s, the NIS has greatly changed (Mowery, 2012) and the various players have had to adapt to these structural changes. Trigger mechanisms are not isolated and exogenous, and the different fields, particularly technological, financial, or institutional (Lorenz and Lundvall, 2006), have changed concurrently (Murmans 2013). Changes in the French NIS have been particularly marked and have had a deep impact on defense firms, which have nonetheless managed to retain their significant position and a specific role in this innovation system.

1.1 Changes in the NIS and the impact on defense firms

Our approach to the NIS is based on Lorenz and Lundvall (2006). According to this view, going from the microeconomic toward the macroeconomic level (and vice versa) and beyond traditional R&D indicators, the capacity for innovation and the adaptability to change depend on diverse types of regulations, as well as the system of science and technology, the financial system, labor market institutions and the educational system. Two major changes within the French NIS have had a strong impact on defense firms since the late 1980s: changes regarding R&D financing and technological changes. The specific impact of these changes on defense firms is due to the particularities of this industry that co-evolved during this period with the NIS. The architecture of the defense industry is structured around two main groups of actors that interact in the development of complex programs: the state (the client and the government agency) and the system integrators. Technological and institutional changes since the 1990s have affected the division of labor and of knowledge in the industry. One of these major changes is the 1997 reform of the French arms acquisition policy, which was driven by budget constraints and increasing technological complexity within the context of the post-Cold-War economic environment. In this new geostrategic context, the so-called peace dividend period, defense equipment purchases were strongly reduced, as was military R&D spending. The 1997 reform was also a consequence of a major change within the NIS, which called into question the policies underlying major technological programs and led to the emergence of new policy-making priorities. In addition, defense firms were privatized and new rules were implemented in the NIS (Guillou et al., 2009).

Changes in R&D financing: affecting especially public and defense funding

One of the major changes of the NIS during the period under analysis was that of the R&D financing system: several reforms of the public funding support program were implemented and new opportunities were created in financial markets. Since the late 1980s, financial markets have developed, with the creation of new markets, products or institutions (derivative markets and contracts, alternative markets, hedge funds, etc.), dedicated in particular to the financing of innovation in the private sector (such as venture capital, mutual innovation funds, etc.) and in the public sector (the creation or grouping of agencies, development of regional or European funding, etc.). This new context, along with reforms for the public support of R&D programs, has made it possible to finance a growth in research activity and has made companies less dependent on direct public financing, particularly in defense. Indeed, during this period, companies had to adapt to a substantial reorganization of public policy for the support and financing of their R&D activity. From the early 1990s, France, similar to other OECD countries, but often in a more pronounced way, chose to substantially revise its policy mix in favor of business R&D. First, the government chose to heavily reduce direct public (*ex ante*) funding, particularly the Ministry of Defense's financing, as previously noted, in relation to the end of the Cold War. Second, beginning in 2004, the government decided to reinforce (*ex post*) indirect public funding primarily by strongly increasing the research tax credit (CIR). These major changes are illustrated in Figure 1. They led to a substantial reform of the size and structure of the public support of R&D in companies.

[Figure 1]

In fact, after the declining trend observed in the 1990s, followed by a stagnation in the early 2000s, the total amount of public R&D financing started to increase again in 2004 and returned at the end of the last decade to the same level as in the early 1990s, reaching 0.38% of GDP in 2011, but with an inverted policy mix (Giraud et al. 2014). Indeed, this upward trend is due to the increase of the research tax credits (CIR), which began in 2004 and surpassed the total amount of direct financing as of 2008 before stabilizing at approximately 0.26% of GDP as of 2009. In proportion to business expenditure on R&D, the total rate of public financing was 26% in 2011, with 8% in direct financing and 18% in tax credits.³ Furthermore, public direct defense R&D funding, which has long been twice as high as direct civil funding at 0.17% of GDP in 1993, became an equivalent funding source in 2011, at 0.05% of GDP. In absolute terms, defense R&D funding was therefore cut from €1875 million in 1993 to €1166 million in 2011. These changes resulted in one of the largest shifts in the public R&D funding model toward European models. They moved the French model closer to the other European ones that had begun developing indirect public R&D funding earlier (Bodas-Freitas and von Tunzelmann, 2008), and they have particularly affected defense firms. Defense financing, which was at the heart of R&D public funding, became one instrument among others in a policy mix prioritizing indirect R&D financing through tax credits.

³ Domestic Business Expenditure on R&D (BERD) stood at €24.7 billion in 2011, for a total in public financing of €7.4 billion, including €2.3 billion in direct financing and €5.2 billion in CIR tax credits (Giraud et al. 2014).

Major impact on R&D projects, especially for defense firms

R&D financing methods greatly influence research activity and innovation (Colatat, 2015, Belin and Guille, 2012). The major changes in R&D financing observed over the period largely explain the way defense firms have repositioned themselves within the NIS. Specifically, they had a strong impact on their type of research projects and the way they are run. In particular, the priority placed on indirect financing and the implementation of programs encouraging collaborative projects (such as the thematic projects funded by the National Agency for Research (ANR), the development of competitiveness clusters, etc.) have led to a more favorable environment for R&D investment for all companies regardless of their characteristics (in terms of size, age, or sector) and have given them more freedom in choosing their research projects and partners. These changes were needed within a context of innovation and fast technological progress. However, although the development of tax credits has compensated quantitatively at the end of the period for the reduction in direct public financing, and particularly in defense, qualitatively speaking, the projects being financed are not the same. In particular, while direct public funding from the Ministry of Defense covers basically defense R&D and is mainly aimed at large companies, indirect tax credits are eligible to finance any R&D project with all companies. Therefore, its development has led to a greater number and diversity of companies receiving funds (particularly in terms of size and sector).⁴ For this reason, and at the same time, the Ministry of Defense redefined its priorities: focusing its funding efforts on financing specifically military technologies, and leaving dual technology financing to civil ministries (Mérindol and Versailles, 2010).⁵ More generally, we saw the end of the era of large-sale programs (Cohen, 2007), with the role of the General Directorate for Armament (*Direction Générale pour l'Armement*, DGA) being redefined (Lazaric et al., 2011) and the development of a knowledge distribution policy (to use the distinction introduced by Ergas, 1987) marked by the emergence of new dynamics, such as competitiveness clusters (Brette and Chappoz, 2007). This has resulted in a decentralization of the decision-making process and the key figures within the NIS. These quantitative and qualitative changes have contributed to reducing the privileged stance of defense firms in the R&D funding plan in France.

Technological and demand changes

Over this period, defense firms were also affected by technological and demand changes. Accelerating technological changes were seen in the increase in R&D efforts made by

⁴ Between the first reform aimed at increasing the tax credit system (CIR) in 2004 and 2011, the number of beneficiaries companies more than doubled. Furthermore, these beneficiaries are mainly SMEs from a wide range of sectors. Thus, among the 15,000 CIR beneficiaries in 2011, only 12% were large companies, and they received about a quarter of this indirect funding. By contrast, that same year, large firms received 91% of defense public funding (Giraud et al. 2014).

⁵ Dual technologies have many potential interests and applications for both civilian and military markets. For example, the military and commercial applications for nanotechnologies and cybersecurity technologies are important and share numerous knowledge components and similar functions.

companies, which can be explained by the growth of their civil R&D spending (owing to the drop in defense financing). This dynamic is presented in Figure 2.

[Figure 2]

The technological complexity brought by the mass implementation of information and communication technologies (ICT) in weapons systems is emblematic of the changes that have taken place within the French defense industry. The technological variables have served to reinforce the weight of ongoing reforms and led to a clarification of the roles of the state and firms in program development. In so doing, they have accelerated the emergence of new modes of production and resource coordination. Because knowledge and capabilities are now increasingly widely distributed, the design and development of an armaments program require the cooperation and coordination of both public and private actors.

Defense firms must also adapt to other technological changes, such as digitalization, the emergence of local and regional dynamics promoted by the creation of competitiveness clusters (Héraud and Lachmann, 2015), or changes in innovation practices. In particular, patents gained strategic importance in companies' industrial strategies (Ayerbe et al., 2012), which over the same period led to an overall strong growth and intensification in patent applications, as highlighted in Figure 3.

[Figure 3]

Demand toward defense firms has also changed. Market globalization coincided with a decrease in global defense expenditure due to the end of the Cold War (Sipri 2016) and a demand progressively driven more by Asia, Oceania and the Middle East. This geographical change in demand has been accentuated in recent years by heavier budget constraints in European countries. In particular, the changes have brought about industrial restructuring since the early 1990s, with different companies grouping together (Dunne et al., 2005). In Europe, especially in France, the process was more complicated due to state intervention. An extensive industrial restructuring occurred (privatization of Thomson-CSF in 1998 and creation of Thales in 2000, creation of EADS in 2000, sales of stakes in Dassault-Aviation acquired in 1981, creation of MBDA in 2001, introduction of SNECMA to the stock market in 2004, creation of SAFRAN in 2005, Nexter in 2006, etc.). This restructuring gave rise to a growth in the size of defense firms, smaller state participation, a more significant valuation for defense firms on financial markets and a greater openness to external markets (Lazaric and Raybaut, 2014). Defense firms had to learn to cope with stronger international competition. What is more, the increasing technological level in both the civil and military fields has resulted in increasingly complex defense products, with a major impact on development costs (Hobday et al. 2005, Kirkpatrick 2004, Harley and Sandler 2012).

Overall, this new environment amplified the need for firms to achieve economies of scale, fostered new forms of networks and increased possibilities for combining skills regarding the NIS and can give rise to new capabilities, as outlined by Fagerberg and Srholec (2008). These transformations rely on a coevolution of technology, institutions and financing, and require that

those involved demonstrate the ability to adapt and learn (Hart 2009; Hekkert et al., 2007).⁶ Once implemented, this dynamic will be well accepted by defense firms, as we will discuss in section 2.

1.2 The role of defense firms in the NIS: new perspectives

Defense firms cannot be identified easily since there is no standard industrial classification for the defense sector. The method of identification used in this study, given its focus on R&D activity, the strong investment in R&D of defense firms and a long-term perspective, is to consider a firm as a defense firm if it receives R&D funding from the French Ministry of Defense. To identify these firms, we use the R&D survey carried out annually by the Ministry of Higher Education and Research (MESR) among French companies.

This method of identification is consistent with that used by other authors, in particular, based on the Ministry of Defense's payments to companies. According to Dunne (1995), the Defense Industrial Base is made up of companies that produce defense or defense equipment for the Ministry of Defense. Three perimeters can be distinguished: 1. companies that contribute to the production of lethal weapon systems and equipment (from R&D to maintenance); 2. companies that provide non-lethal but strategic products (such as fuel); 3. companies that provide everyday products used by armies (such as food). This definition, regardless of the perimeter used, cannot be implemented in this study given the long period of analysis in which changes in the identification of payments were made by the French Ministry of Defense to companies. However, our definition corresponds to the heart of perimeter 1, namely, prime contractors and subcontractors financed by the Defense Ministry, as in Mowery (2012).

Participation in defense R&D activity is not a one-time decision because of the significant investment required (duration of projects, specificity and complexity of products, techniques, procurement contracts, etc.). There is, therefore, a persistence in the defense nature of firms. To address this persistence, we used 3 alternative definitions of defense firms corresponding to 3 samples of defense firms ranging from the broadest (sample 1) to the most restrictive one (sample 3). In sample 1, a defense firm is a company that received R&D funding from the Ministry of Defense at least once in the period 1987-2010 (definition 1). In sample 2, a defense firm is a company that received defense R&D funding at least twice in this period (definition 2). In sample 3, defense nature is assessed annually, that is, for each year of the period, and a defense firm is a company that received defense R&D funding within this year; otherwise, the firm is considered as non-defense for this year (definition 3). The number of defense firms obtained using each definition for all the years of the period of study is given in the appendix.

The results presented were obtained using definition 2 (sample 2) for two main reasons. First, receiving defense R&D funding only once in the period 1987-2010 may not be a sufficient criterion to consider a firm as defense, while receiving such funding each year is clearly a restrictive criterion. Second, the number of firms obtained in sample 2 is the most stable in the

⁶ See Hartley (2013) for consequences on defense firms' definition.

period of study. However, the robustness of our results has been checked using both other samples (sample 1 and sample 3).

A stable effort for defense firms and an increase in R&D spending by non-defense firms

In 1990, defense firms still employed 45% of the R&D staff (researchers and technical or administrative support staff) of French companies and achieved more than half of their R&D spending, whereas in 2010 their shares decreased, respectively, to 24% and 29%. According to the evolution of these R&D aggregates, the relative decline of defense firms' role is the result of a significant increase in non-defense firms' effort, rather than of a decrease in those of defense firms.

In fact, R&D spending in defense firms has been broadly stable in the period. Indeed, it has increased only at the beginning of the period, along with non-defense ones until 1992 (Figure 4). The break observed from 1993 onward is a slight downward trend that can be explained by the decrease in public defense R&D funding observed since 1992 (see Figure 7) and which was followed by a certain stabilization at the end of the period. Hence, R&D spending in defense firms almost returned in 2010 to its initial 1987 level.

[Figure 4]

By contrast, the number of researchers in defense firms has increased over the period studied, but more slowly and gradually than those of non-defense firms as of the early 1990s (Figure 5).

[Figure 5]

The relative decline in defense firms' contributions is then essentially the result of the continuous increase in R&D contributions by non-defense firms since 1992, which defense firms were not able to follow due to the decline in defense R&D funding.

However, the 194 defense firms in 2010 still conduct almost one-third of the R&D of French firms, both in internal or external R&D (Figure 6). Though representing a decreasing share of R&D firms since the early 1990s, defense firms have managed to maintain a substantial R&D effort, enabling them to retain their significant role in the French NIS.

[Figure 6]

Defense firms have retained their role especially in the most preliminary stages of R&D, i.e., research activities, as illustrated in Table 1. Thus, while they have lost half of their share in the development expenditure of French companies over the period (from 56.7% in 1987 to 28.9% in 2010), defense firms better retained their position in applied research (from 45.5% to 30%) and even more so in fundamental research (34.8% in 1987 to 29.1%).

[Table 1]

A reduction in direct public financing for defense firms

These changes are largely driven by the changes to public financing.⁷ The major change was the sharp decrease in direct public funding for R&D since the early 1990s, later compensated for by the sharp increase in indirect financing beginning in 2004. In addition, there was, on the one hand, a tendency to balance out direct financing for non-defense firms due to the sharper decrease in defense funding, and on the other hand, a lesser degree of stability in this funding as of the late 1990s. From receiving the near-totality of direct public funding at the beginning of the period (94.3% in 1987), defense firms saw their share decrease significantly, although they still received more than two-thirds of the funding at the end of the period (71.2% in 2010).⁸ These trends are summarized in Figure 7.

[Figure 7]

2- The ability of defense firms to adapt: reorganization of R&D financing modes and development of new capabilities

Despite the major changes that have negatively affected the public funding directly received for their R&D and the acceleration of technological changes since the early 1990s, defense firms managed to maintain a significant role within the French NIS due to their ability to adapt to this new environment. The analysis of their R&D and innovation activities demonstrates, in particular, their ability to adapt the funding of their R&D, maintain their research capabilities and develop new strategies for innovation.

2.1 Adaptation of the financing structure for R&D activity in defense firms: the decrease in public financing is compensated for by other funding sources

Despite the major decrease in public direct funding, especially from the Ministry of Defense, the financing structure of total R&D expenditures in defense firms is still based on three foundations: direct public financing, own financing (including self-financing, as well as bank or specialized financing), and other financing, which corresponds to funding received from other companies or from abroad.⁹ Defense firms have rather adapted by adjusting the balance between these three parts. In reaction to the downward trend in direct public funding received (from 35.4% of the total R&D budget in 1987 to 17.5% in 2010), defense firms stepped up the share of own financing, particularly at the beginning of the period (from 47.2% to 56.4% over the same period). They have also developed other financing means. In addition, although public funding remains an important source of financing, the loss in stability of this funding means

⁷ These changes can be more marginally explained by the changes made to the R&D survey; in particular, the survey coverage has been expanded by incorporating a greater number of companies, mainly small and medium-sized enterprises (SMEs).

⁸ Direct public R&D financing in defense firms includes not only funds coming from the Ministry of Defense but all public funding received by these companies, regardless of the source (Ministry of Defense, Economy, Research...).

⁹ "Own" financing is calculated by the balance of the total R&D budget from which public and other financing are deducted.

that firms must be more active, diversifying their sources of financing.¹⁰ The evolution of these trends is shown in Figure 8.

[Figure 8]

Reinforcing own financing and other means of funding enables defense firms to reinforce their autonomy, as well as reduce their financial dependence on the Ministry of Defense (Belin and Guille 2006). However, direct public funding from the Ministry of Defense covers basically defense R&D, while all other types of funding are more oriented toward civil and dual R&D. The level of defense R&D funding is then important and necessary for firms to invest in defense R&D. These changes go hand in hand with a strategy based on duality, which corresponds to a type of strategic diversification enabling them to position themselves in complementary, related markets (Mérindol and Versailles, 2016). The goal here is to explore existing technological trajectories and to redeploy certain segments toward new opportunities. Finally, reinforcing own financing is also a condition for survival in what is a global competition, and makes new types of partnerships easier, which are also necessary for renewing existing technological trajectories and acquiring new knowledge (system architecture, security, etc.). In this respect, the example of Thales illustrates these new forms of governance and partnerships in this field (Lazaric and Raybaut 2014). The Thales group, created in 2000 from the former state-controlled Thomson, has disposed of its consumer electronics component (with the creation of Thomson SA) and invested fully in technologies such as aeronautics, space, transport, defense, and security, all the while generating new expertise in service (maintenance and simulation, along with other services) and combining the dual dimension of technologies (civil and military). To succeed in this diversification and these new partnerships, Thales clarified its link with the state shareholder and reinforced its own equity, as well as used and redeployed its R&D activity with large-scale patent applications, enabling them to better identify their technological assets, as well as to give them value in different ways (license, patent, and others) in technological markets.

2.2. Conserving long-term research capabilities and reinforcing their integrator's function

For all French companies, the increase in R&D spending over the period is essentially due to an increase in their applied and fundamental research. In fact, development spending has tended to decrease. These trends are much more pronounced for defense firms (cf. Figure 9).

[Figure 9]

In particular, the increase in their fundamental research investment was particularly high, increasing from 2.5% of their internal R&D expenditure in 1987 to 5.6% in 2010, a growth rate of more than 127% over the period. This choice enabled them to maintain their place in this first stage of research more effectively (as noted above, their share of business fundamental research decreased from 34.8% in 1987 to 29.1% in 2010) than in terms of overall R&D behavior (their share of business domestic R&D expenditure decreased from 52% to 29.6%).

¹⁰ Non-defense firms increased their R&D over the same period, but the funding structure of their R&D remained almost unchanged.

This situation is specific to defense firms, as non-defense firms increased the share of fundamental research in their internal R&D expenditure only marginally in the same period (5.1% in 1987 to 5.7% in 2010). Defense firms, therefore, invested more in conserving their capabilities for the long term and caught up with non-defense firms at the end of the period. In 2010, the share they invested in fundamental research was comparable. This reinforcement of their long-term ability enabled them to retain their absorption ability with regards to public research and to face the growing complexity of military projects.

Reinforcing these capabilities in the long term is essential to retaining their role as systems architects and to take part in a wide variety of technological component development. In fact, as Brusoni and Prencipe (2011) noted, the integrator's job requires reinforcing firms' absorption capabilities. We also understand why defense firms have maintained their efforts in terms of fundamental and applied research in order to be able to combine an even greater number of knowledge assets, both internal and external to the company.

2.3 New strategies for defense firms: diversifying their R&D and innovation, and new IPR management

In France, new forms of governance and a new division of labor in the defense industry have led to the development of in-house technological capabilities aimed at better controlling the value chain (Hobday et al., 2005; Serfati, 2008). The distinction between state and private activities that resulted from the reform of the DGA led to the emergence of new industrial groups (Guillou et al., 2009) and the creation of original types of partnerships to create new assets. The 1997 reform accelerated the reorganization of assets among firms and government agencies in the field of research, and in the division of labor. Firms have repositioned themselves along the value chain through a two-pronged effort toward horizontal integration and vertical disintegration, to enhance the benefits from their innovation activities (Guillou et al., 2009). While the role of firms in the realization of advanced defense research programs has been strengthened, the role of the DGA has been redirected toward following up complex program developments, and more downstream activities related to testing and trialing in the operationalization phases of these programs (Guichard, 2005). Thus, with the exception of the nuclear sector, the interface with scientific research and technological networks is provided by firms (Lazaric et al., 2011). This situation offers possibilities of hitherto unauthorized interaction, based on the creation of complementary assets. In this direction, several strategic changes can be seen since the late 1980s.

The first major change concerns defense firms' strategies and the balance between the revenue of military markets compared with that of civil markets. Some defense firms resorted to strategic diversification of their activity on adjacent markets (civil, such as aeronautics or security, excluding defense). Companies tried to place themselves in a number of markets with a potentially significant technology-product synergy. This is the case of large firms such as the Airbus group, Thales, SAFRAN or Dassault Aviation, for example (see Table 2). These companies today make a large proportion of their revenue in aeronautics, space (civil) and on security markets other than defense. Opportunities in commercial and security markets are

significant, thus explaining why these firms diversified their fields. Using related diversification strategies, as Zhou (2011) describes, requires significant coordination efforts within companies between business units, specialized military activity teams and those dealing with civil activity (Mérindol and Versailles, 2014). These coordination efforts involve sharing research efforts in the company and identifying as early as possible in the innovation process any technologies from military and civil financing received by these companies and which could be re-deployed in adjacent markets. These related diversification strategies also make self-financing of R&D easier: companies tend to finance more on equity when the technological sales base increases as the result of collaborations between civil and military markets. Other defense firms are in different situations, particularly in the land and naval sectors. MBDA, Nexter and Naval Group, for instance, are mono-product companies relying exclusively on the defense market. We should note that Naval Group is trying to enter markets that are far from DCNS core businesses by developing a diversification strategy in civil nuclear energy and emerging renewable energies (see Table 2). Naval Group develops this strategy in order to find new paths for growth: the goal is to find a place (more or less successfully) in new markets, forcing them to acquire new skills and a new economic model. The similarity between naval military construction and these new fields is the ability to handle complexity in the maritime field. On the other hand, the company must be equipped with an entirely new business model, production, design and customer relations methods in order to be successful in its diversification.

[Table 2]

A second important strategic change relates to the growing use of outsourcing for R&D. Since 1987, French companies have been increasingly outsourcing their R&D activity. The same outsourcing trend can be seen in defense and non-defense firms, and at the end of the period, both types of company show similar outsourcing behavior: 13.4% of the R&D expenditure for defense firms and 15.2% for non-defense firms in 1987, compared with 22.5% and 22%, respectively, in 2010.

Defense firms' R&D outsourcing is the consequence of the new industrial reorganization progressively introduced since the 1990s. Large defense firms reposition their activities in the key function of system integration (Hobday et al., 2005). Thus they maintain their own critical R&D capabilities that give them the possibility to coordinate a network of specialty suppliers. They externalize the R&D associated with technological components to the specialty suppliers that are able to perform in their domains. This new organization increases the efficiency of the management of the integration of various technologies into complex systems.

However, outsourcing in defense firms remains specific. They have retained their role as intermediaries between public authorities and the remainder of the French defense technological and industrial base, despite the cuts made to their direct public financing. Indeed, defense firms redistribute nearly all of the R&D spending, which is outsourced and financed by public funds (a stable share of approximately 96% of external R&D expenditure with public funding over the period). Moreover, the use of their R&D outsourcing has a stronger national focus, which has been reinforced over the period. Defense firms have thus strengthened their

role as an intermediary with French companies (61.4% of R&D outsourced by defense firms was for French companies in 1987, compared to 72.9% in 2010), as well as reduced their overseas outsourcing (decreasing from 31.3% to 22.1%), in particular to foreign companies (25.6% to 11.2%). This change is consistent with reinforcing their fundamental and applied research capabilities, which enables them to coordinate a greater network of R&D contractors.

Lastly, other major changes involve the management of intellectual property, which also relies on outsourcing. Defense firms have had to adapt to new market rules and focus on research activity, as illustrated by the new intellectual property strategies introduced (Bessen 2009; Belenzon 2012; Useche 2014; Ayerbe and Mitkova 2008; Ayerbe et al. 2012). Therefore, they have increased their number of patent applications much more significantly than have non-defense firms (+41% from 1999 to 2010) and considerably changed the management of their patent portfolio. Not only have defense firms had to learn to manage a number of R&D collaborations, they have also had to secure their role as technological leaders very quickly by increasing patent applications. To cope with these new organizational and legal tasks and to gain in efficiency while using external skills, some companies have outsourced their intellectual property management. It should be noted that in France, for many years, intellectual property rights (IPR) were negligible or neglected in this field due to government intervention. The reform of the DGA in 1997 and the separation of state and private activities constituted a new challenge for all stakeholders. Activities that came under the state were transferred to the private sector. The best-known example is the case of Naval Group, formerly an arsenal, the Direction des Chantiers Navals (DCN), which moved from being a state shipyard to a private law company in which Thales holds a 35% stake. The need to absorb new capabilities coming from public institutions and their increasing internationalization led to firms repositioning themselves (Guillou et al., 2009) and made it necessary to define a new institutional framework, especially for IPR. In the French case, CRADA (Cooperative Research and Development Agreements) provided little incentive for industrials since the property rights of services lie with the public entity (Ayerbe et al 2014). For this reason, they were redefined in the mid-1990s to create a satisfactory IPR policy at a time when companies were mutating and financialization was on the rise. It became indispensable to facilitate defense firms' internationalization and give them the means for a genuine IPR strategy. Consequently, the DGA's clarification of IPR at the end of the 1990s in favor of private companies (including in numerous domains the abandonment of joint user rights on assets developed during initial research programs funded by the DGA) resulted in more autonomy for companies. Once the DGA had limited the recourse to secrecy and the setting-up of joint user rights with private companies, it was easier for groups to develop their potential internationalization and patent portfolio. Within the DGA, this was achieved without the systematic abandonment of IP for this government agency.

Thales embodies this new approach (Ayerbe et al., 2014). Thales has outsourced its intellectual property department since 2005 by creating a spin-off that handles its patents, as well as the intellectual property of other companies in the field. This unique case shows defense firms opening up, which is a change in culture. Defense firms do not follow dynamics from other sectors but instead create their own models by using new resources to rework their skills. Thales opted for outsourcing in order to be more efficient in the face of the growing complexities seen

in the field of intellectual property and to cope with the company's growing internationalization. Not only did the firm have to incorporate new technological processes following the inclusion of new entities in the group, but it also had to learn to handle the diverse range of intellectual property from the institutional traditions of each country, which greatly exceeded their initial skills. In this context, Thales had to set up new organizational forms of intellectual property use in order to perpetuate their role as a technological leader.

Defense firms have also gained a more important role, acting both in international markets but also being careful to protect their local ecosystem (Bécue et al., 2014). Thales is also in this local and global dynamic and can offer its expertise to smaller regional companies, ensuring their survival in the event of discontinued orders. Firms renewing their capabilities in this way can also come about through "licensing out" agreements, also known as "descriptive capacity," benefiting smaller local companies that use the knowledge of large groups for themselves, applying it in other fields (Azzam et al., 2016).

This dynamic of absorption and desorption demonstrates that defense firms' innovation model is becoming more open and that both internal and external knowledge exchanges are accelerating. Thus, the dynamic of combining knowledge has become a major stake in the face of technological changes and new coordination and transaction costs for multi-product firms working in a global environment (Lundvall, 2016). This makes defense firms change their organizational models in order to better handle their initial function as integrators, as well as to create capabilities, particularly in organizational and legal fields (Zhou 2011; Mérindol and Versailles 2016).

Conclusion

This article provides some evidence that a macro-meso approach of the defense firms within the French system of innovation over a long period of time offers the possibility to better understand what their role is in the context of the late 2000s. This approach is relevant to undertaking a deeper analysis of the structural changes inside the NIS.

The structural changes inside the French system of innovation have impacted rather negatively the role of defense firms since the late 1980s. The relative decreasing trend of their contribution to the R&D aggregates is mainly due to the sharp decrease of public R&D direct funding over the period, above all from the Ministry of Defense. However, defense firms continue to play a key role in the development of the French technological and industrial base. Indeed, defense firms faced up to these changes by demonstrating that they adopted pro-active strategies to remain key actors inside the NIS. They adapted the means of financing their R&D and their research priorities, notably by strengthening their investment in basic research, as well as by outsourcing and rolling out new innovation capabilities. They developed new innovation models in order to take advantage of the new context and of the potential for collaborations between technologies developed for civil and military markets.

Analyzing the French situation has shown that defense firms are far from being characterized by core rigidities. Quite the opposite. They developed new dynamic capabilities by reconfiguring their resources and those of their ecosystem in order to adapt to their new environment and remain a central part of the French NIS, as illustrated by their role in internal and external R&D, in competitiveness clusters, in patent applications, and in research networks.

It might be useful to conduct further, similar long-term analyses in other European countries or cross-country studies to identify to what extent the same tendencies are observable at the European level, or if they are rather country-specific. Structural changes may have a national dimension, as evidenced by the major changes in public R&D financing observed in France.

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Appendix: Changes in the composition of the defense perimeter according to the three definitions

Defense perimeter			
Year	Definition 1	Definition 2	Definition 3
1987	228	185	149
1988	253	210	151
1989	267	219	154
1990	279	222	164
1991	277	222	154
1992	258	206	135
1993	268	213	133
1994	286	226	118
1995	268	212	100
1996	277	211	100
1997	276	206	101
1998	262	194	91
1999	269	196	105
2000	232	178	84
2001	270	192	102
2002	255	183	93
2003	281	191	84
2004	291	194	79
2005	286	195	80
2006	266	184	78
2007	300	201	85
2008	297	201	97
2009	303	196	103
2010	304	194	106

Figures and Tables

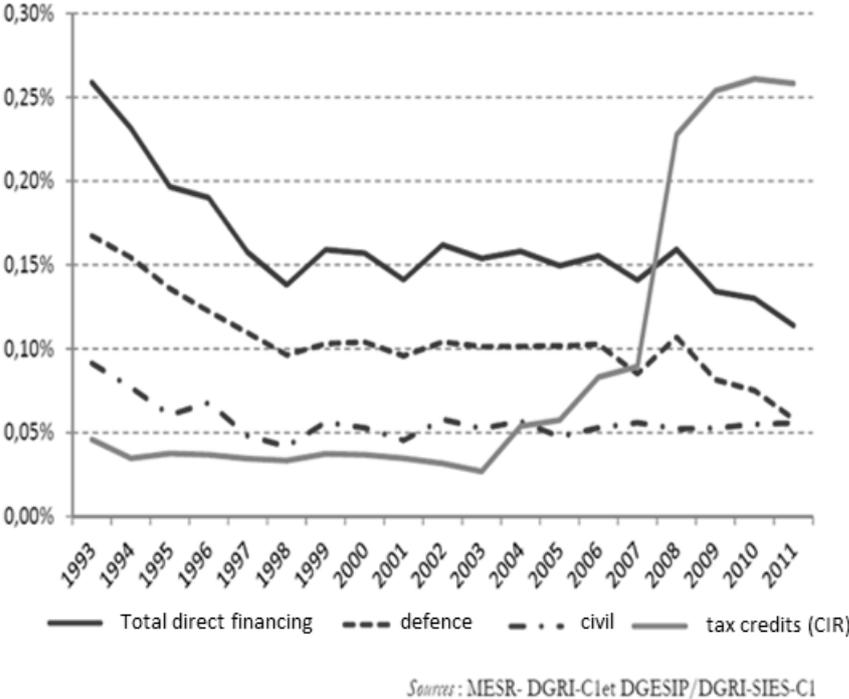
Table 1: Change in share of defense firms in the total expenditure of French firms in fundamental research, applied research, and development

Share of defense firms in	1987	1992	2000	2010
Fundamental research	34.8%	35.5%	31.3%	29.1%
Applied research	45.5%	44.2%	38.2%	30.0%
Development	56.7%	53.4%	39.7%	28.9%

Table 2: Main French Defense leaders and their diversification

	Revenues 2012 Meuros	% DEFENSE	Market segments
AIRBUS GROUP	56 480	21%	<ul style="list-style-type: none"> • Commercial and military aircraft • Commercial and military helicopters • Unmanned aircraft systems (UAS) • Space (satellites, services) • Defense electronics • Cybersecurity
THALES	14 159	60%	<ul style="list-style-type: none"> • Aerospace equipment and systems • Sensors, systems and communications • Weapon systems and ammunition • Training and simulation • Space
SAFRAN (Snecma)	13615	10%	<ul style="list-style-type: none"> • Engines (aircraft, satellite, missile) • Aerospace equipment and systems • Optronics, avionics, navigation systems, • Defense electronics and critical software
DCNS	2 934	94%	<ul style="list-style-type: none"> • Military Naval construction and Naval combat systems • Marine renewable energies • Cooling system for civil nuclear plant
Dassault Aviation	3941	29%	<ul style="list-style-type: none"> • Business jets • Fighter aircraft

Figure 1: Changes in R&D financing in France from 1993 to 2011*



* Giraud et al. (2014).

Figure 2: Changes in domestic R&D expenditure (Source MESR, Ministry of Higher Education and Research)

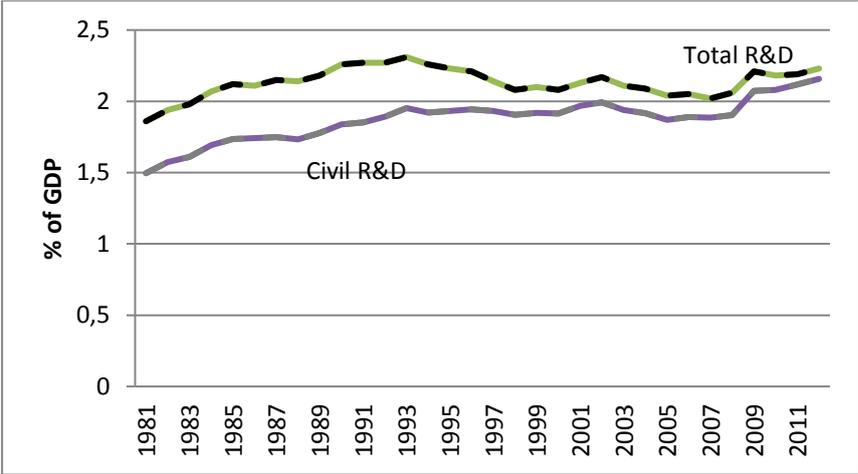


Figure 3: Patent applications at the European Patent Office (Source OECD)

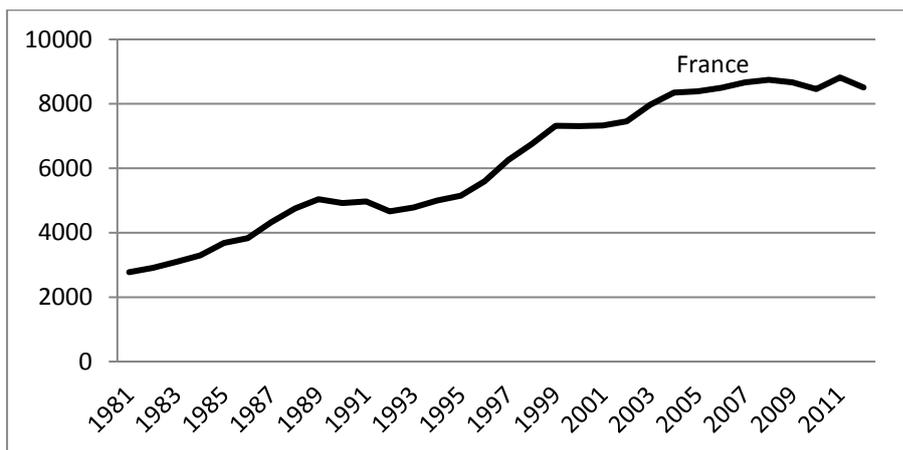


Figure 4: R&D spending by defense and non-defense firms between 1987 and 2010 (Real price, investment price index 2010 = 100, thousands of euros)

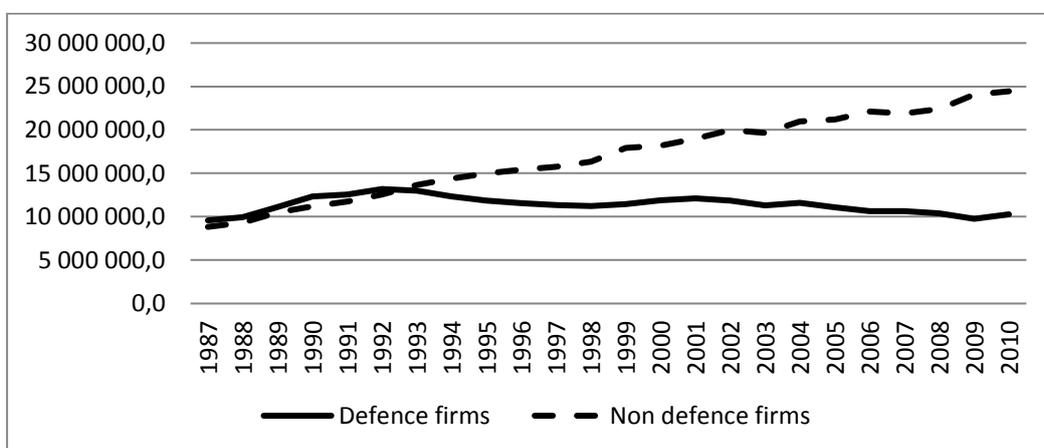


Figure 5: Researchers in defense and non-defense firms between 1987 and 2010

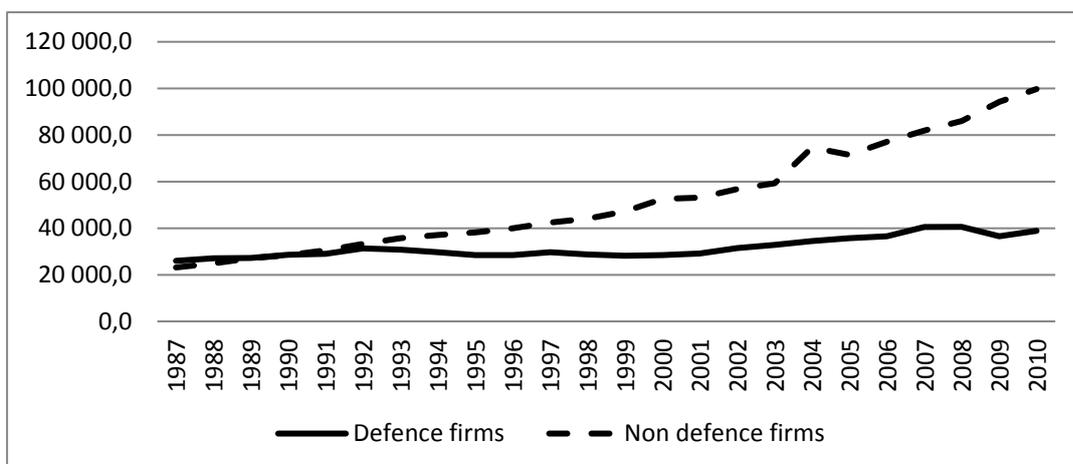
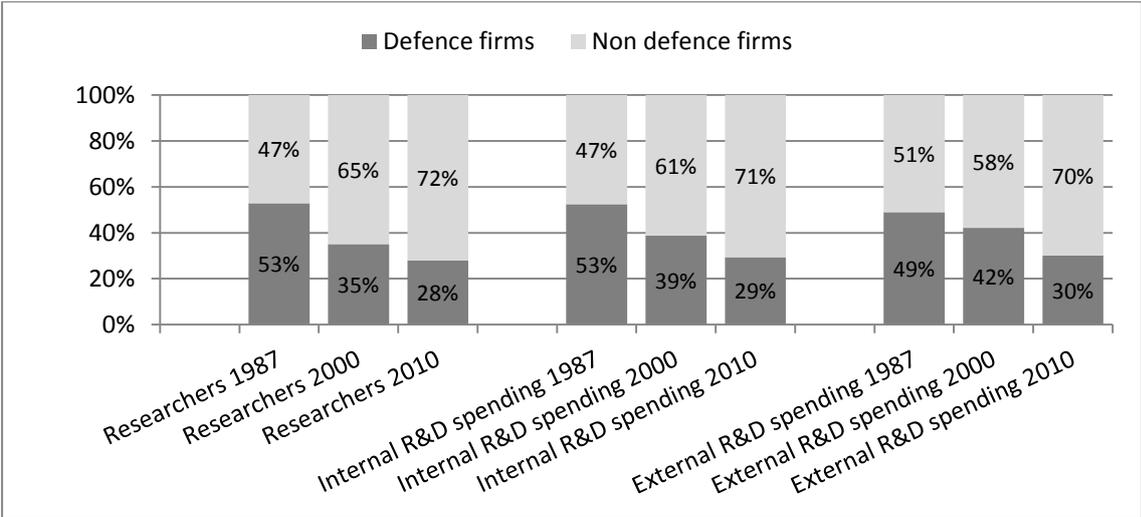


Figure 6: Defense and non-defense firms in R&D in France – 1987-2010



**Figure 7: Direct public financing of Business Expenditure on R&D (BERD)
(Real price, investment price index 2010 = 100, thousands of euros)**

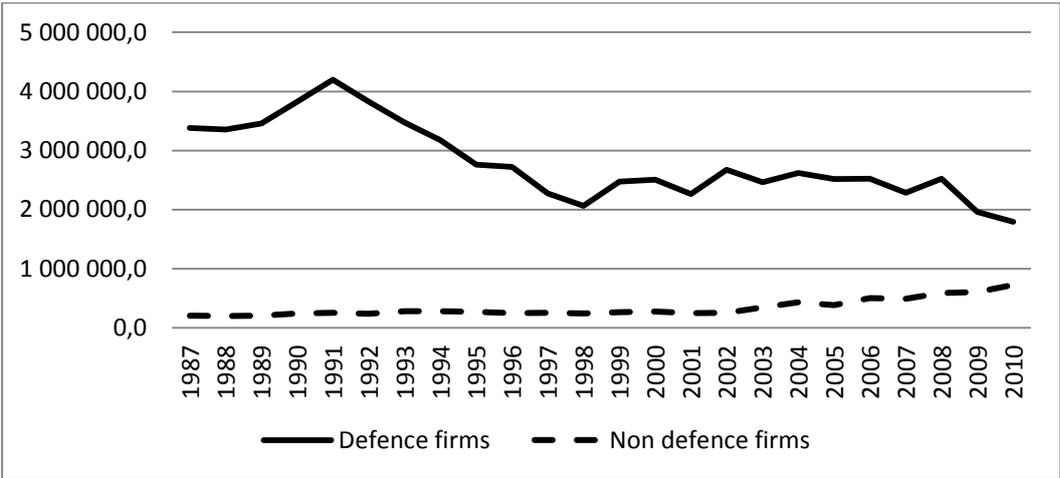


Figure 8: R&D financing in defense firms
 (Real price, investment price index 2010 = 100, thousands of euros)

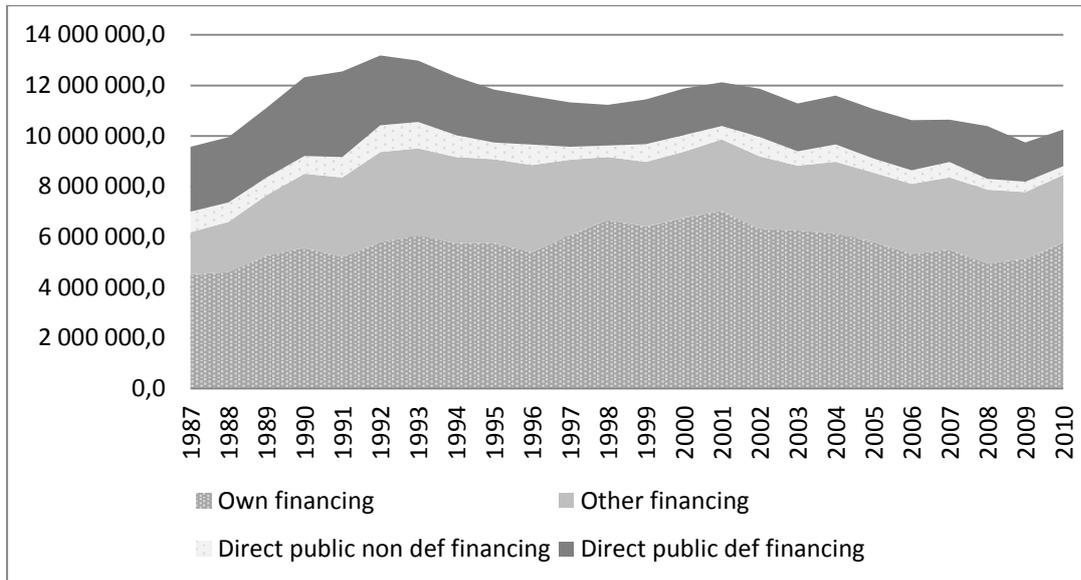


Figure 9: Changes in the breakdown of R&D spending between 1987 and 2010 (growth rate)

