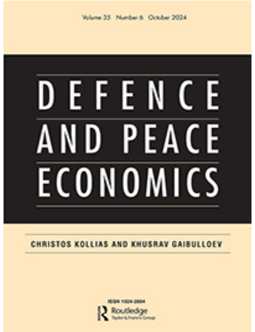

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Assessing the Impact of Military and Civilian R&D on Performance

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ABSTRACT
The aim of this paper is to evaluate the effects of civilian, military and dual (both military and civilian) R&D investments on the profitability of firms. In particular, this paper analyses the role of different types of R&D investment in a sample of firms that collaborate with the Spanish Ministry of Defence. This database contains detailed information about the R&D activities taking place and accounting and financial information. Our final sample consists of 935 observations from 158 firms during the period 2011-2018. The methodology used is the Generalised Method of Moments. The results show that military R&D is more significant than civilian R&D in explaining the financial firm performance in the Spanish defence industry. Moreover, they reveal differences between military and dual R&D and suggest the increasing importance of duality technologies. Finally, taking on board market segment idiosyncrasies does not eliminate, but reinforces, the differences observed. These results help to better understand the effects of R&D expenditure in the Spanish defence sector and are relevant in the current debate about reinforcing European defence capabilities.

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Introduction

The role of R&D investment in the performance of firms is a topic that has been receiving increasing attention following the seminal paper of Schumpeter (1934). Since then, theoretical research has shown that R&D stimulates the performance of firms (Rousseau et al. 2016). However, although most empirical papers find a significant positive effect of R&D activity on firms' results (see, for example, Del Monte and Papagni (2003); Fortune and Shelton (2012) and Lome, Heggeseth, and Moen (2016), among others), there are still several papers that find effects which, while not negative, are less positive or smaller than expected (Pantagakis, Terzakis, and Arvanitis 2012; Gui-Long et al. 2017). Different factors such as a firm's size, business sector and country characteristics, and the range of R&D and performance definitions, are thought to explain these contradictory results. Therefore, a complete understanding of the R&D-performance relationship is still lacking. Paying additional attention to industry-specific circumstances could be helpful to disentangle whether a general relationship between R&D and a firm's performance within industries exists (Boiko 2022). This paper aims to contribute to this area by analysing the relationship between R&D and the performance of firms in a sample of the Spanish defence industry.[1]

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The defence industry has been mainly shaped by regulations and procedures for performing R&D, co-financed by the government in many cases; as the weapon system acquisition programmes are its main customers (Davies and Hobday 2005). Further, the defence industry is, by nature, a strategic national sector since its products are critical to improving defence capabilities and gaining military superiority over potential enemies. National defence procurement systems have been a major driving force for developing new technologies (Cabral et al. 2006). The sophisticated nature of weaponry also implies that designing and manufacturing advanced weapon systems is challenging and requires specific know-how and experience (Gilli and Gilli 2016). Accordingly, defence innovation systems have traditionally been analysed on their own terms, assuming that there is something unique about their circumstances and products.

The relationships between military and civilian R&D activity have been documented by many academics (Mowery 2010). In particular, a positive role for the military in developing civilian technology and economic development has been suggested[2] (Cowan and Foray 1995). Even so, the economic efficiency of military procurement and indirect spillovers into private markets has also been strongly challenged (Edler and Georghiou 2007). The main reason is that only a tiny proportion of military R&D is related to basic R&D. The rest relates to applied research, and such military-specific applications could hardly be adaptable to commercial markets (Malik 2018). Nevertheless, reducing the separation between the civilian and military spheres could create positive synergies, allow for better exploitation of R&D resources and ensure more efficient diffusion of technological innovations to and from the military domain provided they are likely to generate benefits in the other domain. This could be especially relevant in the context of intensified global competition (Bellais and Guichard 2006). The growing interest in dual-use technologies (technology that has both military and civilian applications)[3] originally, and the rapid incorporation of critical civilian technologies into the latest-generation weapon systems more recently indicate that the boundary between military and civilian R&D systems is blurring. Actually, two different phenomena are taking place. On the one hand, defence firms, to achieve their own specific ends, are funding R&D projects that eventually turn into ‘general-purpose’ technologies (Ruttan 2006). In this case, the social value exceeds investors’ economic profits (Martí-Sempere 2018). On the other hand, defence firms are increasingly turning to civilian technology that can then be adapted to military applications (James, Molas-Gallart, and Stankiewicz 2019). Furthermore, many defence firms are now engaging in commercial and dual R&D activities or have developed technological partnerships with civilian counterparts (Hartley 2008; Goldenberg et al. 2019). Interestingly, 48% of the top 25 arms-producing and military services companies worldwide made less than 50% of their overall sales from the defence sector in 2019 (Béraud-Sudreau et al. 2020).

Furthermore, globalisation has permitted defence firms to capitalise on large orders from armed forces around the globe, especially for those firms enjoying economies of scale (Caverley and Kapstein 2012). However, despite market segmentation associated with the sophistication of weaponry, stagnating domestic defence budgets, rising R&D and production costs have intensified competition in global markets (Dunne and Smith 2016) that may have the potential to negatively impact the performance of firms. In addition, the growing connection with civilian corporate activity is transforming defence systems and procurement. Traditional contractors are beginning to feel the pressure as new parties seek to compete for a share of the global market, as is happening in other mission-orientated innovation areas such as space (Robinson and Mazzucato 2018). Hence, decisions on R&D become more crucial. In this setting, the analysis of the effects of different R&D activities becomes relevant since it can suggest policy recommendations to firms and governments that wish to enhance profitability and innovation respectively. It is also an opportunity to shed some light on the nexus debate of R&D investment/performance of firms. This is precisely the aim of this paper.

To that end, the paper analyses the role of different types of R&D investment in a unique sample of Spanish firms that collaborate with the Spanish Ministry of Defence (hereinafter, MoD). These firms (supplier firms) come from a wide array of economic sectors[4] and invest in military, civilian or dual-use R&D. The database contains detailed information about the R&D activities performed which allows the contribution of different types of R&D investments to a firm's profitability separately to be evaluated. The role of government financing, despite its often significant relevance, lies outside the scope of the paper due to data availability.

The analysis of this Spanish sample is interesting for at least two reasons. First, the sector has undergone significant changes, broadening its product range and new and more advanced technologies have been incorporated in recent years (García-Estevez and Trujillo-Baute 2014). In this respect, technological collaboration has increased its importance (Callado-Muñoz et al. 2022a). In fact, 51% of the observations in the sample are only involved in civilian R&D. Second, at the same time, institutional support to facilitate modernisation and to prioritise technologies close to cutting-edge technology and sectors (such as electronics) has helped build a strong technological base and promote internationalisation (Arteaga 2013), allowing the industry to be involved in cross-border European defence programmes. In addition, Spanish industry is actively participating in international technological collaborations sponsored by the European Commission through different initiatives[5] (Bellais and Fiott 2017). In particular, Spain has participated in 42% of the PESCO projects and has headed up four of them.[6] All these efforts together have resulted in a major increase in its export capacity, placing the industry among the ten largest exporters (SIPRI 2020).

As the main results, we find that firms with military R&D (whether exclusively military or in combination with civilian) are more profitable than those only focusing on civilian R&D in the Spanish defence industry. Moreover, when we separate the diverse nature of R&D, it reveals differences between military and dual (military and civilian together) and suggests the increasing importance of civilian technologies adapted to military purposes in Spain as well. Finally, considering segment idiosyncrasies does not eliminate, but rather reinforces, the differences observed.

This paper relates to the empirical research on the economic performance of defence suppliers as well as R&D literature. Previous papers of the former have analysed different aspects and countries. For instance, the financial condition of U.S. contractors (Bowlin 1995), or profitability, see Pepall and Shapiro (1991), Martin, White, and Hartley (1996) and Fonfría and Correa-Burrows (2010) for Canada, the U.K. and Spain respectively. Results on productivity and R&D intensity have also gained attention, see Moura and Oudot (2017) and Belin et al. (2019) and Callado-Muñoz et al. (2022b) and García-Estevez and Trujillo-Baute (2014) among others, for France and Spain respectively. The latter strand of literature has analysed international patterns but they do not distinguish between R&D activities or areas either (Driva, Pawar, and Menon 2000). This paper focuses on an individual country, but it contributes previous approaches by means of disaggregating R&D investments into three different categories, namely military, civilian and dual activities. This classification can help to understand the diversification and collaboration strategies developed by defence contractors considering recent changes in global defence markets and procurement systems. Accordingly, this paper extends previous evidence on the Spanish defence industry by providing an assessment of the incorporation and collaboration with civilian technologies in the performance of firms.[7]

Given its size, the Spanish sector lies in an intermediate position between the major arms manufacturers and the smaller countries in the European Union. The evidence found could help promote the public policies and changes necessary to improve the positioning of the Spanish firms in the European defence landscape.

The paper is structured as follows. We first review the theoretical literature on the relationship between innovation and the performance of firms. Secondly, we describe the data used in the study and present the empirical model. Thirdly, we present the results. Finally, conclusions and implications for future research are made.

Theoretical Background

It is well known that the innovative capacity of a firm can help it obtain a sustainable competitive edge (Acland-Hood 1986; Hilmersson and Hilmersson 2021; Chaithanapat et al. 2022). However, large corporations can operate in different sectors and be involved in the development and production of an array of products. Furthermore, different product characteristics may imply different types of innovation activities and organisation (Eriksson 2000). Accordingly, the R&D practices within a firm or industry can vary widely and these differences can affect the performance of firms (Hughes 1988). Understanding how different types of R&D can help the performance of firms is therefore an interesting unresolved question in the literature.

A notable example of one area of R&D activity that has not been analysed individually is the defence industry. Despite the different types of products seen in the defence market, ranging from commodities to tailor-made products, it has traditionally been considered as a whole. It is different from other economic sectors due to its distinctive features, namely its production for a specific customer and its R&D intensity as a major determinant in accessing relevant cutting-edge technologies to improve national security (Bellais 2009). Therefore, R&D could be very different across defence firms, with some being more focused on tailored-made products while others concentrate on commercial commodities, or even both. In any case, innovation and R&D investments have to be specifically attuned to their customers' needs to ensure effective national defence (Smit, Elzen, and Enserink 1998) and this can lead to greater distinction.

Despite dissimilarities, any kind of R&D performed by firms is designed to better satisfy customer needs and as a consequence creates a significant edge over competitors. Moreover, regardless of the objectives, different R&D practices may share activities, features or funding involved in knowledge and technology generation (Brzoska 2006), which could explain why firms may engage in diverse R&D activities. In this respect, there are two parallel phenomena in the defence industries that are worth considering. First, technologies developed within civilian projects are now 'spinning-in' to the military sector, and second, defence firms are increasingly turning to civilian technology that can then be adapted for military applications (James, Molas-Gallart, and Stankiewicz 2019). The late 20th Century saw the development of new industrial technologies originally targeted at civilian markets but that proved to have relevant military applications. In this sense, biotechnology and nanotechnology are areas of interest in military R&D projects (Molas-Gallart 2012), as are IT systems, super computation, artificial intelligence, robotics and new materials. Therefore, positive synergies that can improve the diffusion of technological innovations to and from the military sector may emerge (Bellais and Guichard 2006). Second, the end of the Cold War has gone hand-in-hand with a new security scenario, involving new threats and hybrid conflicts which 'incorporate a full range of different modes of warfare including conventional capabilities, irregular tactics and formations, terrorist acts, including indiscriminate violence and coercion and criminal disorder' (Hoffman 2007). The intrinsic features of these threats have increased States' awareness about domestic or homeland security requirements. The business prospects in the security sector led defence firms to move into this area, for example, working in surveillance or cyber security solutions, further blurring the boundary between the defence industry and civilian activities, namely the security sector (Hartley 2018).

Accordingly, the distance between military and civilian R&D activities and practices seems to be reducing at an increasing pace (particularly when there are potential applications that can increase investors' profitability). The 'dual use technology concept' was introduced to provide an opportunity to extend the results of research efforts beyond their initial military or civilian goals (Molas-Gallart 1997a). Over the years, the discourse on dual use products has evolved from initial concerns (especially by defence developers) to the active encouragement and promotion of activities that can help maintain a high-tech defence technology core, especially in the case of limited budgets (Te Kulve and Smit 2003).

In relation to the efficient allocation of R&D, the differential contribution of military, civilian and dual R&D to the performance of firms (if any) remains an open question. The efficient allocation of any type of R&D should be based on the expected utility for citizens and society. In the case of military R&D, this may result in higher protection. Although enhanced security for the population and private property is essential for the smooth functioning of markets, and can also promote investment and innovation with positive effects on welfare and wealth, higher security does not necessarily imply a rise in welfare or increased wealth. Furthermore, military and civilian R&D compete for resource allocations because they employ similar resources, such as scientists and engineers. Moreover, previous literature has suggested that there is an effect known as 'crowding out' because the supply of trained scientists and inputs which are necessary for an innovation process is relatively inelastic in the short term and provided the (military) demand for R&D inputs increases, the price of performing R&D will increase and therefore less (civilian) R&D could be sponsored (Cowan and Foray 1995).

In addition, the main characteristics of military-orientated technological development, such as contracts not being awarded through competitive tender, product differentiation, uncertainty and complexity (Martí-Sempere 2015), may have a substantial impact on performance. Uncertainty and complexity have also been associated with a small price elasticity for defence products (Peck and Scherer 1962). Thus, firms involved in military R&D can achieve greater profitability by charging a higher margin due to this low elasticity. Moreover, product adaptation to customer needs has allowed the main contractors to maintain prices above marginal cost (Tirole 1988).

The previous empirical literature has shown mixed results which are highly dependent on the sample and model used. On the one hand, in line with this 'crowding out' argument, there is evidence that defence R&D has a weak economic effect compared with civilian R&D (Lichtenberg 1984; Schankerman and Pakes 1986; Poole and Bernard 1992). On the other hand, studies for Canada and the UK do not show significant differences in profitability for defence and non-defence industries (Pepall and Shapiro 1991; Martin, White, and Hartley 1996). The main exception is Trevino and Higgs (1992) who found that during the period 1970-1989, the profit rates of the top 50 US defence contractors substantially exceeded those of comparable non-defence companies. The empirical analysis of dual R&D has been scant, to the best of the authors' knowledge (by way of exception, see Te Kulve and Smit (2003)), due to the difficulty of classifying R&D activities as military, civilian or 'dual'. Actually, there are a number of grey areas in which the classification of R&D might be in doubt (Molas-Gallart 1997b). Furthermore, comparing military, civilian and dual R&D implies the challenge of finding industry data and similar performance indicators. The lack of information has prevented any detailed analysis or comparisons (Hartley 2018). Much analysis remains to be done before the different effects of diverse R&D investments and their relationships can be understood.

In this article, we make a contribution by analysing three different types of R&D investments in a sample of Spanish firms. Our focus is not whether civilian firms are more profitable than defence firms (or *vice versa*) but to show if different R&D activities contribute differently to the performance of firms. To achieve that, we have taken advantage of a single database that classifies firm R&D activities according to their main objective. Therefore, it allows us not only to provide new evidence on the effects of these different R&D investments on firm profitability, but also to study the differences in impact (if any). In the next section, we describe the data source and the approach followed.

Sample

To achieve our objectives, we use a unique database from the Spanish MoD that provides disaggregated R&D information for the firms that collaborated with that ministry (supplier firms) during the period 2011-2017, together with accounting and financial information. The main advantage in using this source is that it includes all the firms that have collaborated with the ministry over the period analysed. These firms are featured as belonging to the defence industry in a broad sense, including electronics and computer companies, suppliers of commodities and also traditional defence firms. Dunne and Braddon (2008), among others, highlight that in the past the former companies and their R&D establishments had little contact with the military sector and were not considered part of the defence industry. What it is more interesting about this sample is that it provides R&D information differentiating between civilian, military and dual R&D. It also contains information on the market segments to which R&D is directed, according to the MoD sector

Table 1. Distribution of the sample by type of R&D.

	With Civilian R&D	Without Civilian R&D	TOTAL
With Military R&D	272 (29.09%)	149 (15.94%)	421 (45.03%)
Without Military R&D	478 (51.12%)	36 (3.85%)	514 (54.97%)
TOTAL	750 (80.21%)	185 (19.79%)	935 (100.00%)

Source: Own elaboration.

classification. The lack of information relating to other aspects of the defence industry that would also be interesting to examine, such as the type of dual use technology used and the percentage of public R&D financed by the government, makes us concentrate on the differential effects associated with different R&D efforts. Despite its data limitation and short period of availability, we consider it interesting to use this sample of Spanish firms because of its unique information on R&D efforts which is not available from the firms' annual accounts.

This initial information is complemented with other accounting and financial information from the Iberian Balance Sheet Analysis System (SABI) database for the period 2011-2018. During the period analysed, the Spanish economy suffered the consequences of the 2008 financial-economic crisis and European austerity policies. Some firms in the initial sample went bankrupt. Others merged as part of the concentration wave experienced in the defence sector globally. Those firms in bankruptcy or with missing values among the required information have been excluded from the sample. Moreover, since the independent variables included in the model are lagged by one year and also taken as differences, every firm was required to have the information for at least three years. Our final sample consists of 935 observations from 158 firms during the period 2011-2018. This filtering process has reduced the sample size considerably, but the final sample includes those firms that collaborate regularly with the MoD and are responsible for more than 80% of the total R&D collected in the initial base. Thus, we believe that the final sample is still representative of the Spanish sector and guarantees more statistical reliability in the results.

As we expected, Table 1 shows that most of the firms in the sample were involved in R&D activities (96.15%), with civilian R&D being more common than military R&D. Additionally, almost 30% of the sample firms combine civilian and military R&D activities.

Measures

Since our aim is to test the differential impact of different types of R&D investment on business performance, the dependent variable used is Return on Assets (ROA), which is one of the most common measures of economic profitability or performance in general (e.g. Trevino and Higgs 1992 or Fonfría and Correa-Burrows 2010). This is calculated as net profit over the total assets of the firm and it is winsorized at the top and bottom 1% levels to control for potential outliers.

The database distinguishes by type of R&D – military, civilian or dual – according to the MoD classification .[8] Therefore, we define CivilR&D that accounts for the quantity invested only in civilian R&D, MilitaryR&D for military R&D and DualR&D that measures the R&D resources allocated to both military and civilian purposes. These are measured as the logarithm of the expenditures on each type of R&D over total assets. In this way, we can identify whether Dual R&D (civilian and military) is better than specialisation in one type of R&D (civilian or military) and leads to better performance. This gives us a complete analysis of the impact of the different types of R&D on economic performance.

In addition, as explained above, R&D could be very different in different sectors. In the database, there is also information on the market segment which the R&D is directed at. The MoD distinguishes different market segments such us weaponry, missiles, land vehicles, naval vehicles and systems, air, space, electronics and computing or auxiliary.[9] The R&D allocated to each segment may be civilian or military. The analysis of these types of R&D separately could add further insights that can complement the military/civilian R&D debate. Unfortunately, the large number of segments implies that the number of observations in many of them is very small to obtain reliable statistical conclusions. One

Table 2. Main descriptive statistics of the variables used (N = 935).

Variable	Mean	Standard Deviation	Minimum	Maximum
1. ROA	4.70	8.57	−23.48	31.63
2. MilitaryR&D/TotalR&D	0.28	0.41	0.00	1.00
3. CivilR&D	1.51	1.82	0.00	6.39
4. MilitaryR&D	0.52	1.30	0.00	6.25
5. DualR&D	0.64	1.47	0.00	6.51
6. Armament	0.05	0.22	0.00	1.00
7. Platform	0.39	0.49	0.00	1.00
8. Communication & Auxiliary	0.57	0.50	0.00	1.00
9. Size	17.30	2.26	12.67	23.37
10. Age	3.10	0.67	0.00	4.67
Age in number	27.43	18.87	1.00	107.00
11. Liquidity	2.31	2.74	0.47	19.11
12. Risk	4.22	4.72	0.04	23.46
13 High Technology industry	0.37	0.48	0.00	1.00

way to circumvent this problem and take advantage of the availability of information and be able to conduct accurate statistical methods is to group the segments together.

Grouping these market segments into the traditional segmentation: land, naval, air, space or electronic segments is not straightforward, either from a conceptual point of view or for data features either. First, the incorporation and adaptation of cutting-edge commercial technologies has caused the extensive military specifications and standards to be reduced (Molas-Gallart 2001) implying a profound change in the way the military procure military hardware (Ross 2007). Accordingly, land vehicles may share some electronic components with aircraft. This fact is reflected in the MoD classification since it includes some segments that can be considered versatile, in the sense that the products or services developed may have applications in some other subsectors. Furthermore, in this case, the MoD allows the firms to classify themselves in any of the categories affected (DGAM 2016). In other words, if a firm's R&D has helped improve a process associated with the replacement of old batteries, it can include its R&D investment in one of the segment categories where the replacement takes place or in the auxiliary subsector. Hence, the construction of traditional segments is not possible. Despite this limitation, in order to present a more complete analysis, we follow the grouping made in Callado-Muñoz et al. (2022a). In their paper, they analyse all the technological collaborations of the Spanish MoD within all market segments. After a cluster analysis, they conclude that they can be classified into three large groups according to their main objects. The first group is called 'armament' and includes all activities associated with missiles and arms and munitions. The second group is called 'platforms' and it collects those firms whose R&D is related to platforms (land and naval vehicles, air and space) and their electronics. Finally, the third group is called 'communications and auxiliary' and it includes those firms whose R&D is appointed to computing and auxiliary. Accordingly, three different dummy variables are constructed and included in the regression. One potential weakness of this classification is that different levels of technological components may be present together or that sophisticated components concentrate in one segment so that the results could be associated more with a technological level than market sectors. In order to discard this flaw, we introduce a sector control to acknowledge the technological intensity. This sector effect (HighTech) is measured by a dichotomous variable that reflects whether or not the firm belongs to a high- or a medium-high-technology industry[10] (OECD 2011).

As control variables, we use those that have been previously used in the literature. In particular, following Goddard, Tavakoli, and Wilson (2005) and Nunes and Serrasqueiro (2014), we include Size (logarithm of total assets), Age (logarithm of years since foundation), Liquidity (total current assets over total short-term debt) and Risk (absolute value of change in pre-tax profits) since these are firm characteristics that could influence profitability. Liquidity and risk are also winsorized at 1%. Finally, time effects (Time) are also included in the model through dichotomous variables.

The main descriptive variables are shown in Table 2 and the correlations in Table 3.

Table 3. Correlations of variables (N = 935).

	1	2	3	4	5	6	7	8	9
1. ROA	1.00								
2. MilitaryR&D/TotalR&D	0.05	1.00							
3. CivilR&D	−0.04	−0.78*	1.00						
4. MilitaryR&D	0.09*	0.77*	−0.49*	1.00					
5. DualR&D	−0.02	0.43*	−0.51*	−0.22*	1.00				
6. Size	0.03	−0.16*	−0.06	−0.23*	0.04	1.00			
7. Age	0.19*	0.04	−0.20*	−0.03	0.09*	0.31*	1.00		
8. Liquidity	0.20*	0.7*	0.03	0.9*	−0.04	−0.23*	0.03	1.00	
9. Risk	0.04	0.08*	−0.02	0.07*	0.04	−0.10*	−0.11*	0.02	1.00

*$p < 0.05$.

Models

We ran two dynamic panel regression models. Model 1 allows us to identify which type of R&D (civilian, military, dual) is most profitable for the firm while Model 2 goes further and includes the market segments. In particular, we include the *platforms* and *communications and auxiliary (Com&Aux)* dummies, and their interpretation is in relation to the reference variable (*Armament* dummy).

Model 1:

$$\begin{aligned} ROA_{it} = {} & \beta'_1 ROA_{it-1} + \gamma'_1 CivilR\&D_{it-1} + \gamma'_2 MilitaryR\&D_{it-1} + \gamma'_3 DualR\&D_{it-1} + \\ & \beta'_2 Size_{it-1} + \beta'_3 Age_{it-1} + \beta'_4 Liquidity_{it-1} + \beta'_5 Risk_{it-1} + \beta'_6 HighTech_{it-1} + Time'_t + \varepsilon'_{it} \end{aligned} \tag{1}$$

Model 2:

$$\begin{aligned} ROA_{it} = {} & \beta'_1 ROA_{it-1} + \gamma'_1 CivilR\&D_{it-1} + \gamma'_2 MilitaryR\&D_{it-1} + \gamma'_3 DualR\&D_{it-1} + \\ & \beta'_2 Platform_{it-1} + \beta'_3 Com\&Aux_{it-1} + \beta'_4 Size_{it-1} + \beta'_5 Age_{it-1} + \beta'_6 Liquidity_{it-1} + \beta'_7 Risk_{it-1} + \\ & \beta'_8 HighTech_{it-1} + Time'_t + \varepsilon'_{it} \end{aligned} \tag{2}$$

Where i refers to each firm in our sample (1 to 158), t refers to the time period (2011 to 2018) and ε'_{it} is the error, which is assumed to follow a normal distribution. The variables included have been defined previously.

Both models were estimated using Generalised Method of Moments (GMM) (Arellano and Bond 1991) to control for endogeneity and unobserved heterogeneity. In particular, we use a System GMM estimator (xtabond2 Stata module, Roodman (2005, 2009)) that includes as instruments both a first differences transformation to eliminate fixed effects and the correlation between them and the error term, and also variables in levels to increase efficiency (Arellano and Bover 1995), although it could limit instrument proliferation using the ability to 'collapse' (Roodman 2009). It directly offers the Arellano-Bond tests of AR(1) and AR(2); and the automatic difference-in-Sargan/Hansen testing for the validity of subset instruments (to avoid the overidentification and exogeneity of instrument subsets). Finally, it is more suitable for small samples as in our case.

All the independent variables are included as lagged by one year. ROA, the R&D variables and Risk are considered as endogenous variables and the rest of the independent variables are treated as exogenous. We collapse the instruments, use robust estimations and do not include a constant in the model.

Results

Table 4 shows the GMM results for Model 1 on the R&D variables that isolate Civilian R&D from Military R&D and Dual R&D while Model 2 also includes the market segment dummies.

First, we check that these results are robust. To do this, we must verify two conditions: 1) the validity of the restrictions created by using the instruments (by way of a Hansen Test); and 2) the nonexistence of second-order autocorrelation, AR(2).

Table 4. Results of Analyses (N = 774).

	Model 1 ROA	Model 2 ROA
ROA_{t-1}	**0.19†**	**0.18†**
	(0.12)	(0.11)
Militar R&D $_{t-1}$	**1.85****	**1.91****
	(0.88)	(0.82)
Civil R&D $_{t-1}$	**1.62***	**1.69***
	(0.98)	(0.89)
Dual R&D $_{t-1}$	**2.07*****	**2.18*****
	(0.78)	(0.73)
Platform	–	**−3.11****
		(1.54)
Com&Aux	–	−1.29
		(1.54)
High Technology Sector	0.74	1.01
	(0.96)	(0.99)
$Size_{t-1}$	0.25	0.26
	(0.38)	(0.31)
Age_{t-1}	**2.31*****	**2.18*****
	(0.71)	(0.74)
$Liquidity_{t-1}$	−0.03	−0.06
	(0.15)	(0.14)
$Risk_{t-1}$	0.12	0.09
	(0.28)	(0.26)
Time Effects	included	included
Wald Chi^2	**175.84*****	**188.44*****
Specification tests (*p-values)*		
AR(1)	0.00	0.00
AR(2)	0.90	0.92
Hansen (*p-value*)	0.47	0.34

Robust standard errors in parentheses. †$p < 0.15$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In both tests and in both models, the results indicate that the null hypotheses are not rejected. Thus, the results obtained using the System GMM estimator are robust.

The results for Model 1 indicate that all three R&D measures, namely firms with only military R&D, firms with only civilian R&D and firms with dual R&D, have a positive effect on ROA. Interestingly, these effects are different. Comparing coefficients, the most important effect seems to be related to firms that perform Dual R&D. This result reflects the better exploitation of R&D resources and the creation of positive synergies between the two sectors (military and civilian). The incorporation of commercial technology to adapt it for military uses may allow firms to reduce costs and increase efficiency (Molas-Gallart 2012).[11] Military R&D follows in importance, that is, those firms that focus on defence goods, mainly tailor-made, aimed at satisfying the requirements of end customers, namely Ministries of Defence or Governments, which have a low price-elasticity. The least relevant effect on ROA is found for those firms that only focus on civilian R&D. Thus, these results suggest that the Spanish defence industry is a diversified sector, with all kind of R&D being significant for the profitability of firms.

Interestingly, this evidence shows the relevance of duality in the Spain industry, according to recent MoD efforts to promote technological collaborations (Ministry of Defence 2015). Secondly, strict military R&D is more profitable than civilian R&D, as indicated by the larger coefficient. One potential explanation could be associated with the nature of military contracts, since traditionally procurement contracts have used cost-plus schemes, which have guaranteed economic profits. Recently, Western armed forces and procurement agencies have tried to revert this situation and increase transparency and competition in the market. Spain has not been an exception. The recent analysis of the Spanish defence market shows an increasing number of competitive contracts and open tenders (Fonfría and Martín 2018). This evolution has taken place within a reduction in the overall number of contracts year on year due to budget restrictions. Furthermore, the increase in bidders has been shown to reduce the price (González Chapela 2019). A set of regulations was approved between 2011 and 2014 with the aim to promote fair and transparent procurement processes while ensuring equal access to public tenders and extending business opportunities to the SME sector. In this respect, Callado-Muñoz et al. (2022b) show that these legal reforms have exerted a positive influence on firms to reduce costs and produce more efficiently to offset profitability reductions associated with greater transparency and reduced market imperfections. They suggest that this increasing productivity could be related to R&D investments to produce cost-efficient technological developed products to win contracts. Our results add to previous evidence showing how different R&D investments help explain profitability.

The differences observed in our sample could be related to the different objects of R&D rather than its military or civilian nature. In order to discard this possibility, market segment dummies are incorporated in Model 2. As it can be seen in column 2, the introduction of the segment controls does not reduce the differences between military and civilian R&D. On the contrary, the estimated coefficients are larger, whereby the dual coefficient is the one with the highest increase. Therefore, it can be concluded that for the Spanish defence industry all three types of R&D expenditures have a significant impact on performance, although the impact is different in intensity. Furthermore, there are differences associated with the object of R&D. As column 2 shows, the coefficient of *platform* market segment (land, naval, air and space) is negative and statistically significant and the coefficient of *communications and* auxiliary components is not significant. The interpretation of these coefficients has to be made in relation to the market segment that remains outside the model (in our case the reference variable is weapons). The negative coefficient of the platform variable implies that the effect of the *platform* market segment on profitability is lower and significantly smaller than the weapons segment. The non-significant coefficient for communications and auxiliary components indicates that the effect of this market segment on profitability is not different from that obtained in the weapons segment. Thus, weapons activities are more profitable than those in the platform market segment, but we do not obtain significant differences between the rest of the market segments. This evidence could be related to the fact that highly sophisticated weapons components contain significant electronic and communications elements that could be adapted to other uses, suggesting greater opportunities to design R&D programmes and develop technologies with greater 'dual use' prospects, as suggested by Burmaoglu and Saritas (2017).

In addition, the inclusion of the control for technological intensity (HighTech) excludes the possibility that the results found obtain technological differences. Actually, the control variable is positive but not significant, suggesting that in our sample the nature and object of R&D expenditure are more relevant to explain a firm's profitability than technological intensity.

With regard to control variables, the firm's Age has a positive effect on ROA in both models. The firm's Age would reflect its capabilities stemming from greater knowledge, experience, managerial ability or other organisational capabilities. A firm's capabilities, which are a critical factor for the success of R&D, are also dynamic and change with the age of the firm (Fernández-Olmos and Ramírez-Alesón 2017). Additionally, older firms may need to invest in R&D more often to compensate for the obsolescence of their initial advantages (Cuervo-cazurra and Annique Un 2010), something particularly important for those firms that wish to maintain their collaboration with the Ministry of Defence. Finally, our period of analysis is from 2011 to 2018, which followed the financial crisis of 2007-2008 and the austerity programmes implemented by the Government that involved budget cuts in defence and reduced MoD demand. These may have negatively affected the performance of firms since the ministry used to be the industry's main customer. To control this evolution, annual dummy variables have been included. Although their coefficients are negative, as initially expected, they are not statistically significant in most cases. Therefore, the year of investment does not affect performance, at least during the study period, perhaps due to the characteristics of these investments that could cover several years, leading to a reduction in time effects. Despite the inclusion of the time effect, the results are strongly persistent and confirm the different importance of military, civilian and dual R&D in both models.

From Table 4, we obtain three main messages. First, the results support the idea of military R&D (whether exclusively military or in combination with civilian R&D) being more significant in explaining the financial performance of firms in the Spanish defence industry. Second, when we separate the diverse nature of R&D, it reveals differences between military and dual (military and civilian together) and suggests the increasing importance of civilian technologies adapted to military purposes in Spain as well. Third, taking on board segment idiosyncrasies and technological intensity does not eliminate, but reinforces, the differences observed.

Conclusions

This paper analyses the impact of different types of R&D investment on a firm's performance in a sample of the defence industry in Spain. It takes advantage of a unique data source from the Spanish MoD with detailed information about the R&D activities performed, their nature and object. This has allowed us to examine the different contributions made by diverse investments to a firm's profitability. Regarding the defence industry, our analysis indicates the importance of military R&D and it also adds to the debate on the relevance of dual technologies, highlighting the proximity of military and civilian spheres in the Spanish sector. This suggests that R&D plays a fundamental role in providing advanced equipment to the armed forces in increasingly more competitive global markets. In addition, it may also occur that the R&D is developed through collaborations with civilian companies and profits could be more easily achieved in commercial markets. This result is in line with the idea of firms engaging in military and dual R&D activities outlined by Hartley (2008) and Goldenberg et al. (2019).

Related to the literature on R&D activity and a firm's results, the evidence presented adds new insights to our understanding of the R&D-performance nexus: it shows that different industry features appear to be affecting the previous evidence. Therefore, focusing on one economic sector in one country alone has helped shed some light on previously inconclusive evidence on the relationship between R&D and performance, as suggested by Boiko (2022).

However, as with all empirical studies, ours has its limitations. We study the impact of different R&D investments in the performance of firms in a sample of Spanish defence firms. Thus, our results would be affected by the very nature of the Spanish defence sector. Furthermore, additional aspects such us the type of duality or government finance would have been interesting to examine had the information been available. Therefore, the following step in our research agenda is to try to build a larger sample to include more countries with comparable information. Nonetheless, our findings provide interesting and novel evidence on the impact of different types of R&D. First, although Spain has continued to invest heavily in military-related R&D (Schmid 2018), the amounts invested have been significantly lower than seen in the United States, China or France. Even with a lower amount, military-related R&D investments seem to have had an effect on the performance of Spanish firms. Therefore, conducting a comparative analysis in different countries especially with higher R&D investment together with the analysis of the role of government financing is an opportunity for future research.

Second, the European defence industry landscape is changing and the global market has also changed and is expected to evolve accordingly. The European Commission is promoting international technological collaborations as a way to anticipate technological developments (Bellais and Fiott 2017). The Commission's objective is to reduce traditional fragmentation and duplication. The new mechanisms designed to move forward in terms of international collaborations through European funding, in particular from the European Defence fund (EDF), are expected to reinforce national efforts in military R&D investment. One salient feature of EDF is that it includes tailored support for competitive and collaborative projects throughout the entire research and development cycle to create a bigger impact on the European defence capability and industrial landscape.[12] Currently, nearly 34% of the EDF budget for the 2021-2027 period is given over to research.

Third, the High Representative of the EU for Foreign Affairs and Security Policy and Vice-President of the European Commission, Josep Borrell, has recently highlighted that "European defence capabilities do not match those needed for future threats and that R&D investments are not sufficient when compared with other countries' military developments".[13] A better understanding of the effects of R&D expenditure in the Spanish sector shows the timeliness of the study measuring the positive effects of military and dual R&D investments for policy and research reasons.

From a policy analysis perspective, they suggest that the initiatives implemented by the MoD over the years to promote technological collaborations with Spanish firms (Callado-Muñoz et al. 2022a) and to improve the competitiveness of the Spanish defence industry (Callado-Muñoz et al. 2022b) should be reinforced to align firms' legitimate interests to be profitable and to increase the prospects to participate in collaborative R&D projects promoted and financed by the EU that can enhance the national technological base and capabilities. From a research perspective, our evidence points the way for future research as the results of the first round of the EDF, expected by the end of 2022, could provide information to allow us to measure the effects of adjusted R&D by Spanish defence firms in terms of technological partnerships and to evaluate the Ministry's promotional initiatives and suggest changes if needed. There is also the open question to analyse about whether this kind of R&D investment may also have civil applications (Acland-Hood 1986).

Notes

1. The Spanish defence industry is made up by a set of heterogeneous firms that can provide the Ministry of Defence with anything from commodities to munitions and are prepared to technologically collaborate to develop tailor-made products which consume the largest part of the acquisition budget (Duch-Brown and Fonfría 2014).
2. Evidence associated with science, technologies, products and the adoption of military strategies as management tools.
3. In this paper, we follow Molas-Gallart (1997a), who understands dual use technology as technology that has exceeded its initial civilian or military goals, allowing for wider exploitation of research and manufacturing efforts.
4. There are 31 different economic sectors in the sample. Around 25% of the firms belong to the architecture and engineering services sectors. The second activity in importance is related to software products and services. Transport, heavy industry and textile firms (around 4% of the firms) are also present in the sample.
5. Permanent Structured Cooperation (PESCO) together with the European Defence Fund and the Coordinated Annual Review on Defence (CARD) seek to identify opportunities for new collaborative initiatives.
6. 60 projects have been developed since the launch of the initiative. Projects are classified into seven different areas: training, land, maritime, air, cyber, joint enablers and space. Spain has participated in projects in all seven areas.
7. The benefits and the social value added associated with R&D can exceed investors' profits, provided the new developments can be used in other sectors, especially in the case of defence R&D (Martí-Sempere 2018). Unfortunately, information on whether R&D expenditures are spinning in from other sectors or associated spillover effects is not available in the database and we limit the analysis to the potential effects on the performance of firms.
8. This disaggregation level is the main strength of the database. Unfortunately, there are no further explanations about the object of the investment which would allow alternative variable definitions. There is no information on dual technology adaptation to extend original goals either, which would allow for an analysis of the different effects associated with 'the level of duality'.
9. These segments were established in 2010 to define industrial capabilities.
10. According to the OECD (2011), high-technology industries include aircraft and spacecraft, pharmaceuticals, office, accounting and computing machinery, radio, TV and communications equipment, medical, precision and optical instruments. Medium-high-technology industries include electrical machinery and apparatus, motor vehicles, trailers and semi-trailers, chemicals excluding pharmaceuticals, railroad equipment and transport equipment, machinery and equipment.
11. A different question is about the cost effects for the procurement agency. See Molas-Gallart (2012) for a discussion on the matter.

12. https://ec.europa.eu/defence-industry-space/eu-defence-industry/european-defence-fund-edf_en Accessed 10 January 2023.
13. Borrel, J. 'We need to increase European defence capabilities, working better together' https://www.eeas.europa.eu/eeas/we-need-increase-european-defence-capabilities-working-better-together_en Accessed 22 May 2022.

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Appendix: Summary of additional estimations for Robustness Checks

In order to check the robustness of the final model, we also ran model 2 changing the measure of size. First, size was measured with the logarithm of the number of employees (instead of the logarithm of assets) and the results are shown under the model 2a. Second, we also used dichotomous variables to indicate small, medium or large firms (model 2b). In all cases, as Table A1 shows, the results are robust and remain consistent with those obtained previously (Table 4).

Table A1. Robustness analyses ($N = 774$).

	Model 2a ROA	Model 2b ROA
	Employees	Small/Medium/Large
Military R&D $_{t-1}$	**1.63***	**1.77***
	(0.89)	(0.95)
Civil R&D $_{t-1}$	**1.44***	**1.48†***
	(0.86)	(0.93)
Dual R&D $_{t-1}$	**1.94*****	**2.02****
	(0.75)	(1.57)
Platform	**−2.87***	**−3.24****
	(1.59)	(1.51)
Communications & Auxiliary	−1.14	−1.27
	(1.35)	(1.26)
Control variables	included	included
Sector controls	included	included
Time effects	included	included
Wald Chi^2	**182.10*****	**220.06*****
Specification tests (*p-values)*		
AR(1)	0.00	0.00
AR(2)	0.92	0.94
Hansen (*p-value*)	0.33	0.41

Robust standard errors in parentheses. †$p < 0.15$, * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.