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Pistols and test tubes. The effect of public military spending on R&D. Evidence with data from OECD countries between 1985 and 2020

Abstract

This research tries to enlighten the discussion about invest public money on military spending or not. The focus is put on the relation between this spending and the R&D of a country. After reading the previous literature and finding some causal mechanisms that could work as spillovers from the military world to R&D, I carry out a regression analysis to test the hypotheses. To do it, I take data from OECD countries from 1985 to 2020. Then, a positive relation between military spending and R&D is found in this analysis, and the causal mechanisms are also found to be significant.

Keywords

Research, Defence, Government investments.

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1. Introduction

In today›s societies, where voters who are also taxpayers have a say in what they want their taxes to be spent on, one of the most attention-grabbing and polarising discussions is regarding military spending. On one hand, the pacifists and on the other hand the militarists argue over whether the state should invest money in its defence and security, or whether the money should be spent in areas considered more essential by the former, such as health or education. The goal would be to strive for a more peaceful world where armed forces are not necessary. In this case, both sides have put forward valid arguments but nevertheless, I believe that there are many different sides to this discussion, and, like everything in life, the conclusion is neither black nor white. At the same time, I would like to make it clear that my aim in this article is not to position myself on either side, but rather to conduct an econometric study on the effect of public military spending on R&D.

Those in favour of spending public resources on defence often argue that its goal is to not only win wars, but there may be numerous other secondary objectives that seek to aid society: to help in pandemics, to foster national industries, or to develop a country›s R&D (Centre for Studies on Army Defence Culture, 2023).

This ongoing debate makes it essential to investigate and attempt to find extra returns on defence investment. By doing so, it will provide those in favour of maintaining or increasing these investments with arguments in their favour. This study focuses on R&D, with the goal of linking public military spending to increased innovation and development.

Using previous insights from existing literature as well as new contributions, I look for certain causal mechanisms to demonstrate that increased military spending can have spillover effects that would function as positive externalities for society and thus increase the country›s R&D. Therefore, my hypothesis is as follows: public military spending has a positive effect on a country›s R&D, therefore increasing public military spending will encourage investment in R&D. This articles, thus, expects that public military spending will have a positive spillover effect on R&D.

Previous literature on the subject discusses the concept of spillovers, which is translated as *derrames* in the Spanish version of this article, and I hereby explain the reason for opting for this translation. These spillovers involve knowledge flows between sectors. Thus, in the case of public defence spending, the importance of such spillovers has been extensively discussed. Since the defence sector does not have an easily calculable utility in economic terms (national security or protection from natural disasters), spillovers become a useful means of measuring the utility of this public defence investment.

For the analysis, I use data from various OECD countries from different sources, mainly from the SIPRI and OECD databases. The results suggest that my hypothesis is indeed correct and a 1 % increase in military spending four years ago implies an increase of about 0.35 % in the country›s R&D as of today. I also find that the causal mechanisms of the relationship between military spending and R&D are significant. Finally, I attempt to decipher the case of Iceland, which has high levels of R&D but no armed forces and no military spending.

2. Previous literature

In the field of R&D, extensive studies and research have already been carried out over the last fifty years, covering most bases. For this reason, and in order not to deviate from the original objective, this literature review will focus mainly on the two most important research issues: State intervention and military research.

Regarding state intervention in R&D, research may be traced back to the late 1950s and early 1960s. The basic mechanisms of R&D resource allocation were explained long ago, with various theories laying the foundations of the field. As a sector where profit gains are not immediate, may never be achieved and may not generate social value, coupled with problems of imperfect information, R&D investment is plagued by market failures and private firms may be unwilling to reach a social optimum of investment. This would require the State to step in and add an extra pool of public resources. However, empirical analyses until now have failed to confirm these theories, with conflicting and contradictory results (Nelson, 1959; Arrow, 1962).

For example, Lichtenberg (1984) demonstrates that the programme of public contracts funding private sector research with state funds does not actually increase the amount spent by private companies on R&D (in the US in the 1960s and 1970s). Therefore, such a contract programme would not increase a country›s R&D and would simply lower costs for companies.

Another research, in this case on R&D aid programmes to 25 companies in the industrial sector, focusing on energy R&D, rejects the resource crowding out theory. Using data and surveys of the management in these companies, it finds that decreased public R&D funding also entails a significant reduction in company-funded R&D. Their results also do not support the resource crowding out hypothesis, and some of these companies› research projects would not even have been conducted without public participation (Mansfield & Switzer, 1984).

Another programme, the Small Business Innovation Research (SBIR), which provides grant funding for small business R&D in the US, does not really have any effect on increasing small business R&D spending, but only crowds out the spending previously planned by small businesses for R&D purposes. This crowding out is practically one dollar for every dollar subsidised. Moreover, this public subsidy programme also has no impact on employment in the companies researched (Wallsten, 2000).

In Israel, a study using data from 1990 to 1995 has shown that public money spent on R&D in private firms substantially increases R&D investment by small firms but decreases R&D investment by large firms (although the latter is not statistically significant). However, as the vast majority of subsidies end up in the hands of large firms, in the end the total effect of the subsidy programme is much smaller than expected, and for every New Israeli Shekels (NIS) invested in the public programme, only the firms› R&D investment increased by 0.25 NIS (Lach, 2002).

In Sweden in the late 1990s, public R&D subsidies to companies succeeded in increasing the country›s total R&D efforts, but this increase could only be detected in small companies, since they are the ones with the least initial resources for research. The authors of this study were able to rule out the resource crowding out effect due to public funding in small firms but found that large firms did not alter their behaviour because of public subsidies (Heshmati and Lööf, 2005).

To sum up, empirical studies conducted during decades have failed to confirm the theory that the state intervention is required in the distribution of R&D resources to avoid non-achievement of social optima. However, they also do not confirm the hypothesis that this funding is unnecessary and leads to the crowding out of resources that would have been used anyway. There are still many contradictions and no clear conclusions can be drawn.

If we now shift our focus to military R&D, Kaempffert (1941) traces a path from Antiquity to the Modern Age, showing historical examples where military needs have led to great inventions used by society as a whole. From the sewing machine to modern synthetic chemistry, there are many historical examples of military investments that have generated great inventions for society. However, the fact that it is a very good promoter of R&D does not mean that it is a necessary condition as such. For example, biology has never been of primary interest to military research, apart from some branches of medicine, nevertheless society has made great discoveries and achieved important inventions related to biology. This is an example of a field where scientific progress has taken place without conflict-based drivers (Kaempffert, 1941). The aim of this paper is not to demonstrate whether military investment is a necessary or sufficient condition for developing R&D in a country, but only to explore whether it is a good indirect promoter of such R&D and whether it is sufficient to be considered as a possible public policy for increasing research.

Finally, in the literature on R&D, there is a very important concept that may be extrapolated from the new theories of growth: spillovers. In the Spanish version, I have opted to translate it as *derrames* instead of *excedente* or *externalidad* since I consider the former to denote a much more indirect and even unexpected origin than an externality, therefore, it is the term used in the rest of the article. A spillover is a flow of knowledge from one sector/company/country to another that was not previously expected or foreseen. This is also often referred to in economic terms as an externality. It means that the original owners of knowledge cannot appropriate and monopolise their research, as somebody else will also be positively affected by it. For example, a research group may borrow ideas from another group (Griliches, 1979; Griliches, 1991). Or the aerospace industry which, in turn, is closely related to the defence industry, generates beneficial spillovers from its R&D-related activities to the host country where these activities take place. This activity has additional effects such as the spread of knowledge, job creation, increased aggregate demand in the region or aircraft construction, which may be considered the primary objectives (López-Otero and García, 2020).

Spillovers are an even more important part of military R&D. First of all, it must be said that the outputs of defence spending are difficult to measure, due to some of their characteristics. The intangible economic value of national security, the lack of real markets and free competition in the environments in which it is carried out, the uncertainty surrounding the sector (Mowery, 2012), or even its associated moral hazards make it difficult to comprehensively measure its performance and its real utility to society. However, some studies have been able to find tangible economic results that may be attributed to such spending, such as employment, economic growth or international spill-over effects from defence R&D ones. They have also found a positive relationship between public defence R&D spending and productivity or technology growth (Okur, 2013; Moretti, Steinwender and Van Reenen, 2021).

Not surprisingly, I find that, in the previous literature, the main interest and focus is on the relationship between public R&D (military or otherwise) and general R&D. I find it intriguing that there are not many authors interested in finding out whether there is a relationship between overall public defence spending (not just military R&D) and the overall level of R&D in a given country. Not all defence-related R&D spending needs to come from public sources. For example, a government may spend billions of dollars on an arms programme via a direct purchase from a company. In this case, there would be no direct public expenditure on R&D, but the money spent by the government on the programme will end up in R&D in one way or another. The company in charge of the programme has to research new systems for the weapons it sells, so it shall hire researchers, fund experiments or purchase technical research equipment, in short, increasing its R&D investment. This is the aim of this article; to try to find a relationship between overall public defence spending and a country›s R&D. To summarise, the research question formulated to carry out the research would be as follows: How does public military spending affect a country›s R&D?

3. Theoretical discussion

My expectation regarding the above question is that public military spending will have a positive spillover effect on R&D. Thus, the hypothesis of the study will be the following: Public military spending has a positive effect on a country›s R&D, therefore increasing public military spending will encourage investment in R&D in that country.

The causal mechanisms affecting R&D are related to the concept introduced in the literature section: spillovers. These would work in a kind of butterfly effect where, for example, an initial purchase of tanks by the armed forces ends up increasing the country›s R&D. Let us discuss this further:

Public defence spending operates through two different types of investments: human capital and military assets (there may be others, such as certain contracted services, but the aforesaid two are the most responsible; see the 2023 budget of the Spanish Ministry of Defence where most of the expenditure is recorded either under salaries or under actual investments). The providers of these investments may be Armed Forces personnel or the defence-related industry. If we focus on the latter, when the defence industry receives supply contracts for goods and services to the armed forces, it has to develop its production capabilities. These capabilities may cover many different departments, but the one that is of interest here is R&D. This department will then require funding for research materials, for the facilities where experiments will be carried out and above all, for recruiting researchers and people with research-related careers, of which a high proportion are university students.

As a result, the demand for researchers will increase in the country (and not only thanks to the defence industry, but also to Armed Forces' investment in human capital that is not outsourced to private companies). This increased demand will also create an increased incentive for young people to opt for research jobs, as there will be increased vacancies and, due to higher demand, higher salaries. On the other hand, GDP per capita will increase due to the development of the defence industry, similar to any other industry. This increase in GDP per capita will boost the overall economy, which means that there will be even more funds available for other sectors to invest in more researchers, more education and, ultimately, in more R&D. In conclusion, the money spent by the government on certain defence-related programme will cause a snowball effect, where there will be spill-overs from one activity to another, creating a multiplier effect where the original spending which is not directly on R&D, has a positive effect on the country's R&D.

In summary, the three causal mechanisms are as follows:

– More public military spending More researchers More R&D.

– More public military spending More people with tertiary education More R&D.

– More public military spending More GDP per capita More R&D.

Arguably, these causal mechanisms are the same for all sectors of the economy; greater investment in health services leads to increased R&D; greater investment in agriculture leads to increased R&D; or greater investment in the energy industry leads to increased R&D. This is most likely true; however, this paper focuses only on the defence sector. It would be highly interesting for future research to examine whether, and to what extent, other economic sectors can also generate positive spillovers.

A simplified form of the causal mechanisms described above are shown in the following figure:

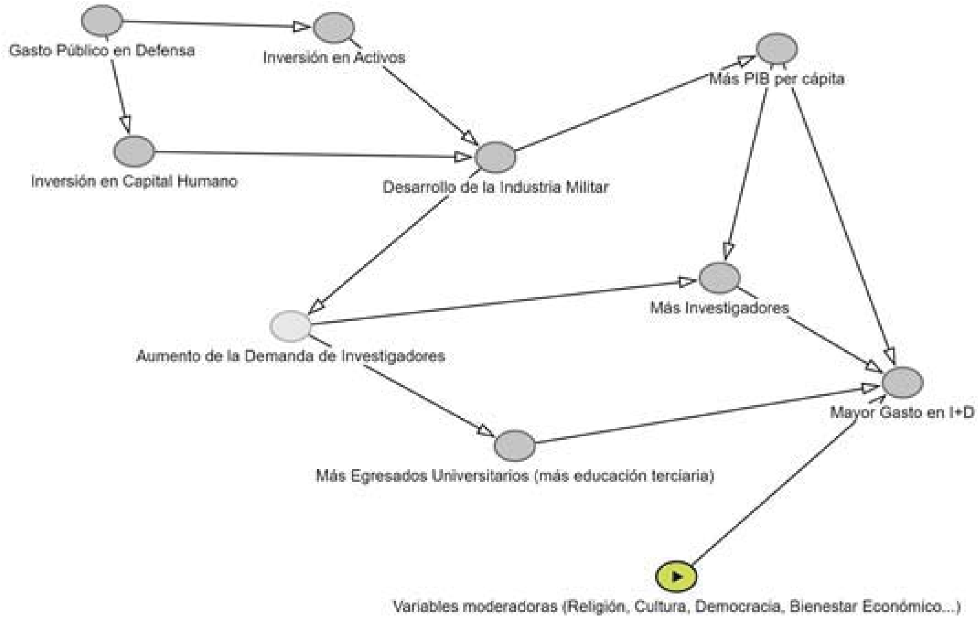

Image 1. Diagram of causal mechanisms

4. Data and method

This research conducts a linear regression with the OLS (Ordinary Least Squares) method. For readers unfamiliar with econometric techniques, a linear regression is a mathematical model used to find a relationship between a dependent variable, a set of independent variables, and an error term. The OLS method consists roughly of finding the parameters by minimising the squared errors. The unit of analysis used will be the country-year, for the period of years 1985 to 2020. The country group chosen consists of 34 OECD countries plus Argentina, the People's Republic of China, Romania, Russia, Taiwan and South Africa. The countries have been selected purely based on data availability and has no scientific basis. Moreover, due to a lack of data, many values are missing in many developing countries (China, Chile...) and there are other countries (Baltic Republics, Russia, Slovakia...) that were created after the start of the dataset compilation. For these reasons, the data used have a limitation: the excessive weight of Western developed countries. This may complicate the fact that this research is not applicable to all countries in the world, but only to developed countries. However, I believe that this does not change the purpose of this work nor its validity. The only thing to be done is to impose the condition that the results obtained are more valid for developed countries than for developing countries.

The dependent variable will be a country's R&D. The ideal operationalisation would be the total R&D expenditure of a country, however, there are several endogeneity problems associated with this approach: public defence expenditure also includes a percentage of public R&D expenditure, which would be endogenous to total R&D expenditure. To solve this problem, the dependent variable will be operationalised in two different ways: Private Gross Domestic Expenditure as a percentage of GDP (Priv_ID) and Patents per capita (Pat).

Gross Domestic Expenditure on R&D as a percentage of GDP is a variable showing all the money spent on R&D by private companies in the country. To operationalise it, the data on "Business gross domestic expenditure in R&D in PPP dollars of 2015" was extracted for each R&D type from the OECD data, and the percentage of GDP accounted for by this expenditure was calculated using the OECD GDP data.

To operationalise Pat, data on the total number of patents created in each country each year was extracted and this number was then divided by the total population of each country each year, taken from the OECD. As the numbers were logically very small and not very unevenly distributed, logarithms were taken of this variable, for a better distribution for the purposes of analysis. Thus, the coefficients given by the regression will be changes in percentages and not in absolute terms, which for this variable is probably more interesting.

The reason for taking two different variables for this concept is that Priv_ID has endogeneity problems (explained later in more detail) with one of the causal mechanisms (Researchers = Invs), and the regression of patents per capita is likely to be more valid. The sources for both variables are OECD datasets.

The independent variable will be public military expenditure as a percentage of GDP. In this case, adding lags to the variable to see if the effects are different over the years. Thus, a variable t-i is obtained, where i is the number of years that have passed since this expenditure was made. For example, if expenditure was 1 % in 1985, it will appear as follows: in 1985, t = 1; in 1986, t-1 = 1; in 1987, t-2 = 1; in 1988, t-3 = 1; in 1989, t-4 = 1. And, by doing this for each t, a dataset is created with lagged information up to four years. The source of this data is the SIPRI military expenditure database. It was decided to take logarithms for the OLS regressions, and therefore Iceland (which has 0 % expenditure, as it has no armed forces) disappears, making it a dataset of 39 countries. Point 6 of this article briefly discusses the special case of Iceland.

Figure 1 displays the trend in military spending for the group of forty countries that have been chosen, plus the average in bold. Iceland is displayed in pink to highlight its zero expenditure over the years. As the dataset starts in 1985, the end of the Cold War, the average has a decreasing trend until the turn of the millennium, and then stabilises at around 2 %, which makes sense as many of these countries are part of NATO, which imposes a 2 % public military expenditure for its members. Two lines persist above the rest: US (blue line) and Russia (red line). Until 2014, the US outspent Russia, and since the Invasion of the Crimean Peninsula, Russian spending has surpassed that of the US. Greece (purple line) overtook both powers in 2021, which is in the midst of a rearmament programme due to tensions in the Mediterranean Sea. On the other hand, Ireland (green line), Luxembourg (orange line) and Mexico (light blue) are countries that spend the least on defence as a percentage of GDP, and therefore their lines are permanently at the bottom of the graph. The pink line at the bottom is Iceland, which, as noted above, has no public defence spending.

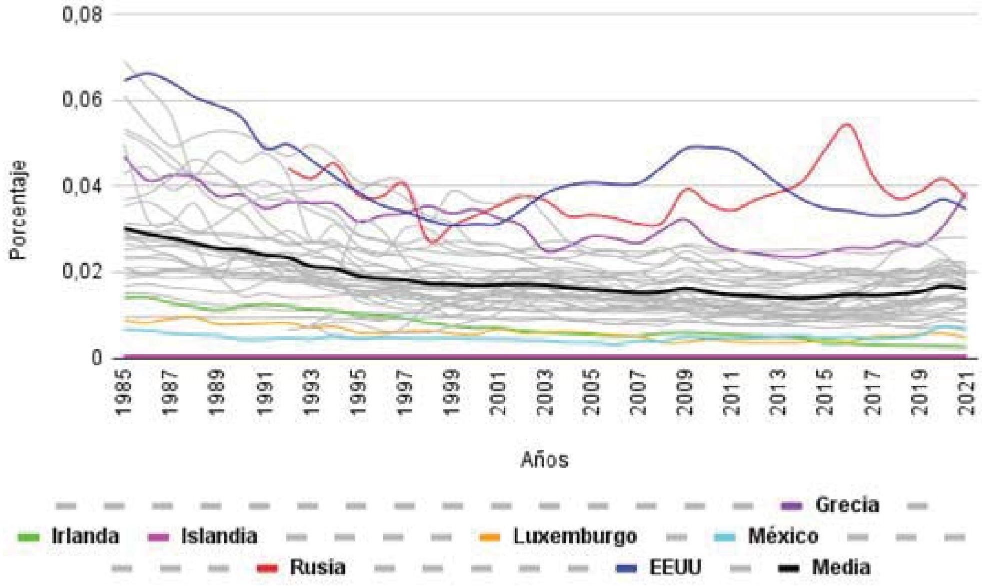

Image 2. Public Military Expenditure as a Percentage of GDP. Source: Author's own based on SIPRI data

In terms of domestic R&D spending, figure 2 shows that there are large differences in the trend across countries, with no clear trend as in military spending. It has increased in some countries such as Austria, China, Denmark, Taiwan; with South Korea standing out above the rest, also reaching the highest point of all the graphs at 5 % of GDP. What we do not see are downward trends, in countries without constant increases in recent years, the percentage has stabilised in each country according to its economic capacity and the distribution of sectors in its economy.

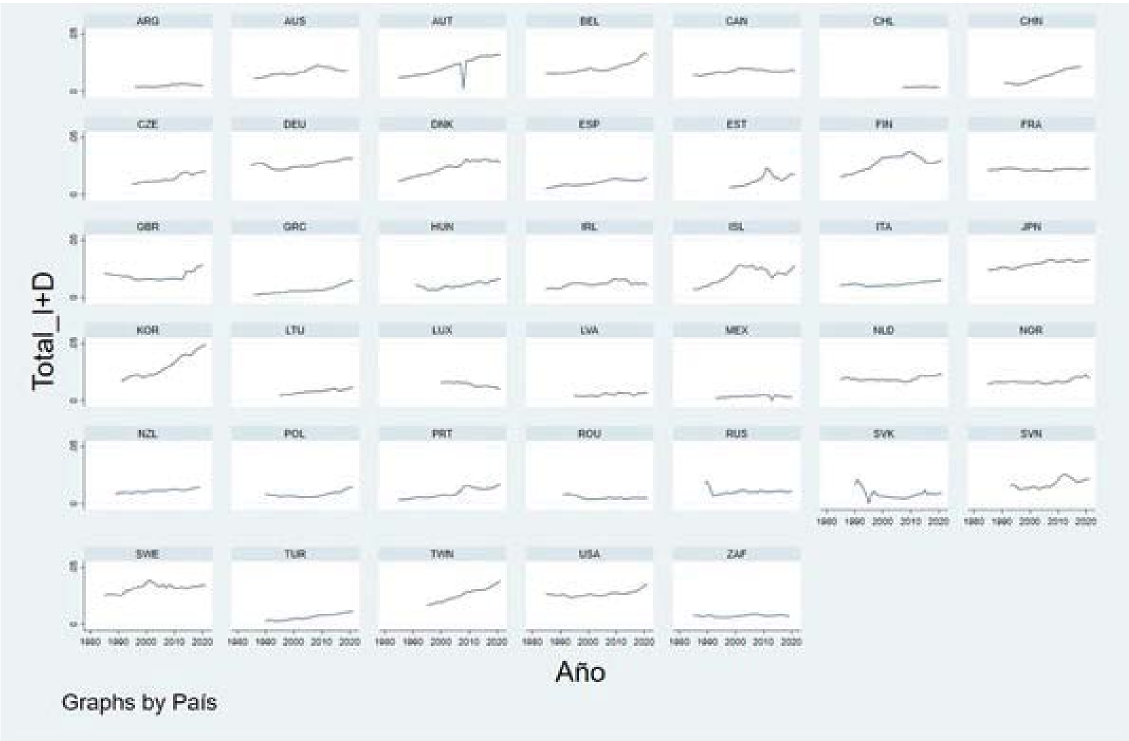

Image 3: Gross Domestic Expenditure on R&D as a Percentage of GDP. Source: Author's own based on OECD data

The three causal mechanisms that will serve as operationalisation of the spillover concept are the following, as mentioned above: A country›s tertiary education, operationalised as the percentage of adults aged 25-64 with tertiary education (Edu), a country›s GDP per capita divided by 1000 (Gdpc/1000), and a country›s number of researchers, operationalised as the number of researchers per 1000 employees in a country (Invs). The data are sourced from the OECD. Finally, some control variables which were found to be important in increasing a country›s R&D were added to the regression: labour productivity (ProdTra), Foreign Direct Investment (FDI) and levels of democracy (Dem).

As this analysis works with percentages, it was decided that the OLS model to be used would be a log-log model, in order to view the effects of percentage increases in public military spending. For readers less accustomed to econometric models, if both the independent variable and the dependent variable are in logarithms, the coefficient ($_{\beta 1}$) that will emerge from the analysis may be interpreted as follows: if the independent variable increases by 1 %, the dependent variable will increase by$_{\beta 1\%}$. Absolute increases would be less interesting, as the normal way to explain state spending on defence is usually as a percentage of GDP.

It is also necessary to explain why there will be an OLS model for each lag of the independent variable and not a single model including all lags. There is strong multicollinearity (some variables are perfect transformations of others) between the different lags (for obvious reasons, as each lag is simply a perfect transformation of the previous lag) and no improvement in the results is obtained by placing them in separate regressions. What happens is that all the effects of military spending are shifted to the last lag, rendering them statistically insignificant. For this reason, there will be five different regressions for each dependent variable and the differences between them will be shown. Thus, the resulting OLS models for the analysis are as follows:

$$LPriv\_ID = \beta 0 + \beta i * Lt\text{-}I + \alpha_1 * Edu + \alpha_2 * Gdppc/1000 + \alpha_{3*} Invs + \gamma k * Ck$$

$$LPat = \beta_0 + \beta i_1 * Lt\text{-}I + \alpha_1 * Edu + \alpha_2 * Gdppc/1000 + \alpha_3 * Invs + \gamma_k * C_k$$

Where i{0,4}, k{1,3} and C_k are the control variables.

5. Results

5.1. *Dependent and independent variables*

In this section, the results of the OLS regressions on the collected data will be shown and interpreted. In both tables 1 and 2, the regressions are complete with all causal mechanisms and all controls included. The only difference between the different models is the independent variable used: from Lt (military expenditure in the current year) to Lt_4 (military expenditure four years before the current date). REG 1 and REG 6 use Lt and the rest go in the order shown in the tables.

Table 1 reveals that all the lags of military spending are statistically significant, and there are no major differences in either their coefficients or the R-squared of their models. The highest coefficient is 0.4229 and the lowest is 0.4081, a difference of only 0.0148. According to this model, a 1 % increase in public military spending in the current year would mean a 0.41 % increase in Gross Domestic Private R&D Expenditure as a percentage of GDP. For a 1 % increase in public military spending four years ahead of today's date, the increase in R&D will be 0.42 %.

Table 2 displays a similar situation. All lags are statistically significant and the R-squared are even higher, reaching 0.67 at REG 10. However, in the case of patents we can clearly see the effect of lags, as the difference between the coefficient of Lt and Lt_4 is 0.039 % which, translated into real values, means that for a 1 % increase in military spending, patents will increase that year by 0.36% and four years later there will be an increase of 0.40 %. Moreover, the R-squared of the models increase as we add more lags to the independent variable.

Tabla I: Modelo de Comparación con LPriv_ID

	(1) REG1	(2) REG2	(3) REG3	(4) REG4	(5) REG5
Lt	0.4141***				
	(0.0459)				
Edu	0.4551	0.5183	0.5735	0.6455	0.6972
	(0.3762)	(0.3733)	(0.3739)	(0.3681)	(0.3627)
Pibpc1000	-0.0102***	-0.0103***	-0.0104***	-0.0105***	-0.0105***
	(0.0030)	(0.0030)	(0.0031)	(0.0030)	(0.0030)
Invs	0.1710***	0.1703***	0.1694***	0.1686***	0.1681***
	(0.0142)	(0.0142)	(0.0142)	(0.0141)	(0.0140)
ProdTra	0.0098***	0.0097***	0.0096***	0.0095***	0.0093**
	(0.0028)	(0.0028)	(0.0029)	(0.0029)	(0.0028)
IED	0.0640	0.0453	0.0082	-0.0131	-0.0334
	(0.2412)	(0.2400)	(0.2355)	(0.2401)	(0.2330)
Dem	0.0111	0.0109	0.0105	0.0104	0.0115
	(0.0240)	(0.0237)	(0.0242)	(0.0242)	(0.0241)
Lt_1		0.4126***			
		(0.0461)			
Lt_2			0.4081***		
			(0.0457)		
Lt_3				0.4120***	
				(0.0458)	
Lt_4					0.4229***
					(0.0455)
_cons	-4.5868***	-4.5991***	-4.6193***	-4.6149***	-4.5880***
	(0.3153)	(0.3180)	(0.3176)	(0.3175)	(0.3148)
N	546	546	546	545	545
r2	0.5816	0.5818	0.5812	0.5834	0.5868
F	131.8519	133.7481	134.1840	136.1027	140.5015
ll	-494.8653	-494.7120	-495.1257	-493.2626	-491.0449

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table I. LPriv_ID Comparison Model

These results confirm the initial hypothesis of this research and also add an interesting extra point to the results. The impact of public military spending on a country's R&D increases over the years, so it is not an immediate effect, but a delayed effect. This is clearly logical. Investments do not usually have immediate results and it often takes some time from the time a project is funded to the time it begins to yield returns, whether economic, military or research.

The effect of military expenditure on R&D may be deemed significant. A 100 % increase in the defence budget increases private R&D by 42.3 % and patents by 40 % in four years. This may not seem very high, as the increase is smaller than the investment, but it should be borne in mind that the main purpose of military spending is to increase military capabilities. This means that R&D increases are nothing more than indirect effects or positive externalities, and an increase of 40 % can be considered high.

Tabla II: Modelo de Comparación con LPat

	(1) REG6	(2) REG7	(3) REG8	(4) REG9	(5) REG10
Lt	0.3621***				
	(0.0804)				
Edu	1.3555*	1.4120*	1.4611*	1.5047*	1.5532**
	(0.5926)	(0.5901)	(0.5894)	(0.5852)	(0.5815)
Pibpc1000	0.0329***	0.0328***	0.0328***	0.0329***	0.0330***
	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0050)
Invs	0.2211***	0.2203***	0.2193***	0.2184***	0.2181***
	(0.0216)	(0.0215)	(0.0215)	(0.0214)	(0.0213)
ProdTra	0.0140**	0.0138**	0.0137**	0.0135**	0.0132**
	(0.0051)	(0.0051)	(0.0051)	(0.0051)	(0.0051)
IED	-0.0989	-0.1069	-0.1308	-0.1379	-0.1476
	(0.4122)	(0.4128)	(0.4085)	(0.4079)	(0.4002)
Dem	0.1605**	0.1601**	0.1594**	0.1597**	0.1603**
	(0.0519)	(0.0518)	(0.0522)	(0.0522)	(0.0520)
Lt_1		0.3666***			
		(0.0785)			
Lt_2			0.3675***		
			(0.0762)		
Lt_3				0.3836***	
				(0.0737)	
Lt_4					0.4014***
					(0.0720)
_cons	-13.8462***	-13.8305***	-13.8241***	-13.7592***	-13.6995***
	(0.6451)	(0.6444)	(0.6373)	(0.6327)	(0.6278)
N	705	705	705	704	704
r2	0.6686	0.6691	0.6692	0.6696	0.6709
F	242.2672	245.2270	242.1665	238.0562	239.8552
ll	-1035.8094	-1035.3160	-1035.1480	-1032.5395	-1031.2337

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table II: LPat Comparison Model

For readers less accustomed to econometric models, the summary of the results in Section 5.1 is as follows: using both L_Priv_ID and LPat, this research finds that public defence spending positively affects a country's R&D, with 99 % confidence. The R-squared (the coefficient measuring the quality of the regression) is greater than 0.5, which implies good research quality.

5.2. Causal mechanisms

With regard to causal mechanisms, the following analysis may be made. In all models for both dependent variables, GDP per capita and researchers are statistically significant at the 99.9 % level. These two clearly function as causal mechanisms, i.e. spillovers, for our regression. However, education level is significant at 5 % only in models with patents as the dependent variable. There may be various reasons for this, for example, the increasing proportion of skilled workers who have undergone vocational training rather than a university-based one. These workers are often more necessary than ones with university education, but they are not included in the tertiary education statistics. In any case, this question requires a separate investigation and is not part of the purpose of this article. The conclusion regarding causal mechanisms is that GDP per capita and the number of researchers per 1000 employees can be considered good spillovers for the effect of public military spending on R&D, but not the share of adults aged 25-64 with tertiary education.

To understand which causal mechanism is stronger, new regressions were run for both dependent variables (LPriv_ID in REG 11, REG 13, REG 15; and LPat in REG 12, REG 14, REG 16). These regressions are the same as those done before, but in each regression, one of the causal mechanisms disappears, and then they are all compared to each other to see the changes that occur. The independent variable chosen for these regressions is Lt, without any lag. However, because the rest of the Lt-i are transformations of Lt, the results reached in this part are the same.

The results, in table III, show that, in the case of patents, the strongest causal mechanisms (those that most reduce the R-squared when removed from the regression) are education level and researchers. The difference in R-squared is almost 0.06 for researchers and 0.045 for educational level. GDP per capita makes a minor difference, as the R-squared only drops by 0.025 when it disappears from the regression. It is, thus, concluded that, in the case of patents, the most efficient causal mechanisms are the level of education and the number of researchers, although GDP per capita is not far behind.

For private R&D, GDP per capita is again the least decreasing R-squared when taken out of the regression. Its effect is now even smaller, as the R-squared drops by 0.01. For education, the drop is around 0.056, which means that it is a stronger causal mechanism for private R&D than for patents. However, where we can see a clear difference is with researchers. When researchers are removed from the regression, the R-squared drops to 0.15. This means that researchers per 1000 employees is a very good predictor of private R&D in a country.

However, this is not as bright as it might seem, as it is very likely that there is endogeneity between researchers and Priv_ID. When there are more researchers in a country, there will be more research output and therefore the percentage of GDP made up by private R&D will be higher. However, the reason why there would be more researchers employed in a country is probably because there has been a prior increase in R&D investment and therefore the increase in the share of GDP has preceded the increase in researchers. In the end, it is not possible to know in which direction the causality is headed or which action came first (at least with these regressions). As endogeneity is only related to a causal mechanism and not to the independent variable, the model with LPriv_ID need not be discarded, but this detail makes the model with LPat more reliable.

Concluding the results, it may be stated that the model with LPat as the dependent variable is better overall, as the R-squared is higher, does not suffer from endogeneity problems, and allows us to see the lagged effect of military spending. This effect is significant and increases over the years. For a 100 % increase in military expenditure, the number of patents in a country increases by 36.21 % in the same year, or by 36.66 %, 36.75 %, 38.36 % and 40.14 % if the expenditure was made one, two, three or four years earlier respectively. This is a very strong spillover effect because, as previously mentioned, the original intention of military spending is to increase military capabilities, and the whole effect on R&D is just a positive externality. With these results, it may be said that the initial hypothesis of this study is confirmed, as it shows that military public spending does indeed have a positive effect on a country›s R&D, and indeed, increasing military public spending will increase R&D investment in the country.

Tabla III: Comparación de derrames/mecanismos causales

	(1) REG11	(2) REG12	(3) REG13	(4) REG14	(5) REG15	(6) REG16
Lt	0.3988***	0.2752***	0.4659***	0.2196**	0.3994***	0.2950**
	(0.0482)	(0.0813)	(0.0518)	(0.0807)	(0.0564)	(0.0901)
Pibpc1000	-0.0067	0.0426***			-0.0148***	0.0277***
	(0.0035)	(0.0070)			(0.0040)	(0.0063)
Invs	0.1809***	0.2218***	0.1763***	0.2084***		
	(0.0111)	(0.0182)	(0.0149)	(0.0212)		
ProdTra	0.0107***	0.0181**	0.0040*	0.0328***	0.0213***	0.0298***
	(0.0030)	(0.0057)	(0.0020)	(0.0044)	(0.0036)	(0.0058)
IED	-0.0776	-0.5786	0.0047	0.0672	-0.0797	-0.3827
	(0.3018)	(0.6024)	(0.3494)	(0.2866)	(0.3649)	(0.5461)
Dem	-0.0655***	0.0344	0.0019	0.1891***	0.0599	0.2102***
	(0.0121)	(0.0289)	(0.0223)	(0.0562)	(0.0311)	(0.0587)
Edu			0.1307	2.1983***	3.2249***	4.8025***
			(0.3782)	(0.5854)	(0.3481)	(0.5578)
_cons	-4.0423***	-13.1400***	-4.3419***	-14.5170***	-5.0683***	-14.5936***
	(0.2258)	(0.4417)	(0.3267)	(0.6585)	(0.3921)	(0.7215)
N	672	930	546	705	573	771
r2	0.5256	0.6232	0.5699	0.6434	0.4318	0.6041
F	141.7268	239.9469	158.3684	172.8914	66.3689	144.2739
ll	-680.3957	-1468.8877	-502.4002	-1061.6075	-605.3103	-1194.5886

Standard errors in parentheses
* p<0.05, ** p<0.01, *** p<0.001

Table III: Comparison of spill-overs/causal mechanisms

6. The case of Iceland

Although the aim of this study is not to explore why Iceland has no military spending, but instead high levels of R&D, the following section provides some guidelines that will be used to assert a final point to be made. This study does not seek to find the necessary and/or sufficient conditions for R&D to develop in a country, but simply to demonstrate that military spending is a plus, an addition that positively affects R&D.

Iceland is a fairly innovative country, exceeding the OECD and EU average. The biggest drivers of its R&D are mainly the energy and fisheries sectors, with a clear focus on sustainable fisheries and clean energy generation processes, although it has other sectors spearheading innovation such as health, agri-food and ICT (Koutsogeorgopoulou and Cho, 2021).

From 2019 onwards, the Icelandic government has been implementing a 10-year innovation plan called The Innovative Iceland. The main pillars of this plan are to improve the finances of innovative companies, with a clear focus on start-ups; promoting education and training of the workforce, in order to create new professional skills and attracting qualified personnel to the island; improve the country›s infrastructure, market access and legal framework; and, above all, to create a sense of innovation in the Icelandic mindset. The Icelandic government perceives individual ingenuity as one of the focal points of the country›s scientific progress. This will be achieved by teaching school students to develop this feeling and by disseminating scientific achievements to the general public (Koutsogeorgopoulou & Cho, 2021).

On the other hand, Iceland›s population is around 375 000 and unemployment is close to 3 %. This means that, in order to foster growth, it is vital to increase productivity, as very large growth cannot be fostered based on population growth or on the inclusion of the unemployed in the labour market. A final issue explaining their large R&D investment as a percentage of GDP is the relatively small size of GDP in absolute terms. This means that R&D as a percentage of GDP is likely to be higher.

This small section of the article was mainly intended to add that public military spending is a highly important source of R&D for a country, thanks to spillovers, but that it is not, however, a necessary condition. A country can have very high levels of innovation and R&D and spend nothing on defence, Iceland being a clear example of this.

7. Conclusions

The initial purpose of this research was to contribute to the discussion on public defence spending. The original idea was to find out whether this expenditure has an impact on a country›s R&D. To this end, a thorough literature review shed light on the concept of spillovers or, indirect flows of knowledge between sectors.

In the case of this research, spillovers from increased public defence spending to R&D would be driven by three causal mechanisms: university education, the number of researchers in the labour force, and GDP per capita. To find out whether this is really the case, this study ran a linear regression on data from more than forty OECD countries over 35 years.

The econometric results confirm the initial hypothesis and show that a 100 % increase in public military spending leads to increases of 36-42 % in R&D, the stronger the further back in time the investment was made. Furthermore, the best model for finding this effect is the one using the logarithm of patents per capita and that the most important causal mechanisms are researchers and GDP per capita.

For future research, it would be interesting to further explore the idea of these causal mechanisms and try to find some others that could explain this relationship, or even attempt to find the reason why these causal mechanisms work as observed. It would even be interesting to examine after many lags does the effect of military spending on R&D start to fade.

Moreover, as already discussed in the theoretical framework, it may be interesting to apply this same research model to other expenditures in the country: does the agricultural industry generate R&D? does health spending influence R&D? does a country›s audiovisual production influence R&D? After the effect of each sector is individually studied, it would be interesting to predict a whole index to detect the sectors with the greatest impact on R&D, in order to predict the direction to be taken by public policies seeking to increase R&D.

The importance of this research lies in its novelty, as theoretical models on this topic had previously been discussed, but large-scale empirical studies had not yet been carried out. Thus, this work provides an empirical confirmation of theories that predict military investment as a major promoter of scientific development. This topic is hotly debated in society today, and the results obtained may be of great interest to advocates of defence investment, who will be able to argue that governments have another reason to continue funding military programmes without a purely warlike objective, but rather with a broader vision.

Further empirical studies should be conducted to find out what other sectors are positively affected by such military investment. For example, it would be interesting to research impacts of public military spending on other factors such as social welfare, economic performance, happiness, health and so on. Public investment in defence has many utilities beyond national security, and it is our job to uncover them.

Index of acronyms (in order of appearance)

I+D	Research and Development
OCDE	Organization for Economic Cooperation and Development
SIPRI	Stockholm International Peace Research Institute
PIB	Gross Domestic Product
MCO	Ordinary Least Squares (econometric technique to find the parameters of a linear regression)
Priv_ID	One of the variables dependent on the study: Gross Domestic Private Expenditure as a percentage of GDP
Pat	One of the study dependent variables: Patents per capita
PPP	Purchasing Power Parity
t-i	The independent variable of the study: Military public expenditure as a percentage of GDP. To check the time effect, the variable is delayed, making each i one year backward.
OTAN	North Atlantic Treaty Organization
Edu	One of the causal mechanisms: Percentage of adults aged 25-64 with tertiary education
Pibpc/1000	One causal mechanism: GDP per capita of a country divided by 1000
Invs	One causal mechanism: Number of researchers per 1000 employees in a country
ProdTra	One of the controls: Labour productivity
IED	One of the controls: Foreign direct investment
Dem	One of the controls: Level of democracy
L(variable)	The logarithm of a variable. LPat for example would be the logarithm of Pat
R-cuadrado	A statistical coefficient that determines the quality of the model. Its value determines the percentage change in the model-attributable dependent variable.
TICs	Information and Communication Technologies

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