Defence and Peace Economics

ISSN: 1024-2694 (Print) 1476-8267 (Online) Journal homepage: www.tandfonline.com/journals/gdpe20

Military Technology, Defense Spending and Modernization of the Armed Forces: The Case of Spain, 1891-1935

José M. Ortiz-Villajos & José J. Martos-Gómez

To cite this article: José M. Ortiz-Villajos & José J. Martos-Gómez (2024) Military Technology, Defense Spending and Modernization of the Armed Forces: The Case of Spain, 1891-1935, Defence and Peace Economics, 35:7, 883-907, DOI: 10.1080/10242694.2023.2198912

To link to this article: https://doi.org/10.1080/10242694.2023.2198912

Published online: 09 Apr 2023.

DEFENCE AND PEACE ECONOMICS
2024, VOL. 35, NO. 7, 883–907
https://doi.org/10.1080/10242694.2023.2198912

Routledge
Taylor & Francis Group

Military Technology, Defense Spending and Modernization of the Armed Forces: The Case of Spain, 1891-1935

José M. Ortiz-Villajos[a] and José J. Martos-Gómez[b,c]

[a]Department of Applied and Structural Economics & History, School of Economics and Business, Complutense University of Madrid, Pozuelo de Alarcón, Spain; [b]Facultad de Ciencias Empresariales - Carrera de Administración, University of Lima, Lima, Peru; [c]School of Economics and Business, Complutense University of Madrid, Madrid, Spain

ABSTRACT

A central aspect of the modernization of the armed forces is innovation in military technology, which in turn has been closely linked to defense spending. However, the connection between these variables has hardly been analyzed quantitatively. This is due, in part, to the scarcity of statistical data on military technology. This paper has constructed this indicator for the case of Spain based on patents registered in the country. This has allowed us to conduct a VAR model analysis to explore the relationship between defense spending and military technology and between the latter and the modernization of the armed forces from the late 19th century to the eve of the Civil War. Estimates have revealed that defense spending did not have a causal effect (in the Granger sense) on military patents, but there was a relationship in the opposite direction; that is, technological innovation preceded spending. In addition, it has been found that the patents that most influenced spending were foreign patents. On the other hand, there is evidence of a positive effect of military patents on the modernization of the armed forces, with foreign patents being the most influential in this case as well.

ARTICLE HISTORY
Received 27 August 2022
Accepted 31 March 2023

KEYWORDS
Military technology; patents; defense spending; military modernization; Spain; VAR models

JEL CLASSIFICATION
H56; O31; O34; N43; N44

Introduction

Spain lost its last overseas possessions –Cuba, Puerto Rico and the Philippines– when it was defeated in 1898 by the United States. This event demonstrated the industrial and technological superiority of the American country. In Spain, many voices were raised calling for the modernization of the armed forces, which had fallen behind, in addition to being depleted by the war. This required an increase in military spending, but the war effort had left the state coffers exhausted, which led to a few years of budgetary austerity. This changed at the end of the first decade of the 20th century with the reconstruction plan for the Navy (1908) and the beginning of the Moroccan conflict (1909). The expansion of military spending made it possible to increase and improve the material endowment of the armed forces, largely through the importation of foreign weaponry and technology. It is reasonable to think, then, that in those years defense spending allowed for an increase and renewal of armaments, which in turn would have boosted the modernization of the armed forces (López-Rodríguez 2019). However, this has not been analyzed quantitatively. Doing so will serve to confirm whether and how the relationship between these variables actually occurred. This is the main motivation for the present study.

CONTACT José M. Ortiz-Villajos jmortizv@ucm.es Department of Applied and Structural Economics & History, School of Economics and Business, Complutense University of Madrid, Pozuelo de Alarcón, Spain

Specifically, our objective is to find out whether from the end of the 19th century until the Civil War –a period in which the Spanish economy closed the gap with the most advanced economies (Carreras and Tafunell 2021; Tortella 2000)– defense spending was related to innovation in military technology and whether this influenced the modernization of the armed forces. Although the exercise is limited, since it focuses on a specific country and period, its interest transcends the specific case by providing new evidence on a relevant issue in defense economics –the connection between spending, technology and military modernization– which has hardly been studied empirically.

After this introduction, the second section offers a review of the literature. The third describes the sources and data for the study. The fourth presents the model used in the analysis, based on the vector autoregressive technique (VAR). The fifth shows the results and the sixth concludes.

Literature Review

The relationship between defense spending, military technology and modernization of the armed forces has hardly been expressly analyzed, but it has been dealt with in one way or another in numerous studies. Thus, the relationship between defense spending and military technology is indirectly addressed in quite a few works on the so-called military-industrial complex (Dunne 1995; Hooks 2008; Weber 2001), public armament procurement (Hartley 1998; Saal 2001) or the defense policy of specific countries (Bitzinger 2021; Bitzinger and Raska 2015; Gholz and Sapolsky 2021). Some studies with a historical approach have also clearly pointed out the connection between both variables (Ferguson 2001, 30-38; Hoffman 2012) and others have done so indirectly, such as works on the so-called fiscal-military state (Duffy 1980; O'Brien and Hunt 1993; Stone 1994) or on the determinants of military spending and war economies (Eloranta 2007, 2019). Evangelista's (1988) well-known work on the arms race argued that the initiative in the creation of new military technologies in the United States came from scientists and technicians, while in the Soviet Union it came from the state. From this it could be deduced that in the first case the technology preceded the state effort and in the second case the opposite was true (MacKenzie and Evangelista 1989). However, neither this nor the other works mentioned have analyzed this relationship quantitatively.[1] This may be partly explained by the scarcity of data on innovation in military technology, since data on defense spending are abundant.[2]

Defense R&D has been used as an indicator of military technology innovation (Hall and James 2009; James 2009; Mowery 2010), although it is an imperfect measure, since only part of R&D spending translates into innovation (Álvarez and Fonfría 2000, 113-115). Patents are a better reflection of innovation, but the available data on military patents have limited temporal and content coverage. For example, Sullivan Faith (2013) collects patents filed by U.S. Department of Defense laboratories between 1960 and 2010, but not all defense industry patents. Acosta, Coronado, and Marín (2011, 2013) analyze a sample of 582 military technology patents registered in Europe and the United States between 1998 and 2003, taken from the Derwent Innovations Index (DII), which contains information on some patent classes since c. 1980. In any case, these papers do not study the relationship between defense spending and military technology. Schmid (2018a) does: with data from 52 countries between 1975 and 2007, also obtained from the DII, he finds –without this being the primary objective of the work– a positive and significant effect of defense spending on innovation in military technology (Table 3, 51). Hall and James (2009), using military R&D data, suggest the same for the British case between 1990 and 2000. This is precisely what we suspect may have happened in Spain at the time of our study.

Although about the Spanish case there are numerous works on defense spending and military industry innovation both for recent times (e.g. Álvarez and Fonfría 2000; Fonfría 2014; Molas-Gallart 1997, 1998; VV.AA. 2000) and for the first third of the twentieth century (e.g. Cubel 1994; Díaz Morlán 2019; Gómez Mendoza 1988; Gómez Mendoza and López García 1992; Goñi Mendizabal 2007, 2008; Lozano Courtier 1997; Martos Gómez and Ortiz-Villajos 2022; Molas-Gallart 1992; San Román 1999), none have quantitatively analyzed the relationship between these variables.[3] This is what this paper aims to do based on the two historical series. The one on defense spending is available in several sources (see Sabaté Domingo 2015, 2016), but not the one on innovation in military technology,[4] which we have constructed ad hoc from the historical database of patents registered in Spain, as explained in detail in the following section.

As for the relationship between military technology and modernization of the armed forces, we are not aware that it has been expressly analyzed either, but it has been implicitly analyzed in various works on geopolitics and military technology (Bellais 2013; Bitzinger and Raska 2015; Blanken and Lepore 2011; Schmid 2018a, 2022; Van Creveld 1991), as well as in historical studies on the rise of the West (Hoffman 2012; Kennedy 1987; Parker 1988). But where it has been most discussed is in works on military innovation, a concept related to the modernization of the military in its various facets: doctrinal, strategic, human, material, and organizational (Cheung 2021; Griffin 2017; Grissom 2006). For Posen (1984), a pioneer in this field, military innovation is driven from politics, while for Rosen (1988, 1991) it comes from the military establishment itself through competition between branches. For other authors, cultural and social factors are more determinant (Farrell and Terriff 2002; Kober 2015). In any case, all approaches consider technology as a relevant factor of military innovation. However, neither has the relationship between these two variables been analyzed quantitatively.[5] In addition to the scarcity of military technology indicators, the difficulty of quantifying military innovation or modernization is added in this case.

In the case of Spain, López-Rodríguez (2019) shows that technology played a relevant role in military innovation during the first third of the 20th century, particularly during the Moroccan War (1909-1927). For her part, Sánchez Sánchez (2006) shows how France contributed to the modernization of the Spanish army between 1948 and 1975 through the transfer of weapons technology and military training. However, neither work makes a quantitative analysis or provides a concrete measure of military modernization. But there is one study that has proposed an indicator in this regard (Martos Gómez and Ortiz-Villajos 2022). This will be the one we will use to empirically test whether technological innovation –measured with military patents– boosted the modernization of the armed forces, as seems to be evident from the two aforementioned works.

Sources and Data

As mentioned, this study uses three variables: defense spending, modernization of the armed forces and innovation in military technology. The data on defense spending are taken from the *Cuentas del Estado Español* (Spanish State Account Books) (Instituto de Estudios Fiscales 1976; 1979, 1982). At the time studied, Spain had two military ministries, the Ministry of War (Army) and the Ministry of the Navy, each with a separate budget account. For the calculation of total defense expenditure, we have taken not the budgeted expenditure, but the actual expenditure (the 'recognized and liquidated obligations') corresponding to the accounts mentioned above. The evolution of this variable at constant prices is shown in Figure 1.

As a measure of the second variable, the modernization of the armed forces, we have used the modernization index calculated by Martos Gómez and Ortiz-Villajos (2022), consisting of the ratio of equipment to personnel expenditures. This is a limited indicator, as it only reflects one aspect of military modernization, but an important one.[6] In any case, it is the only one available to date. The index has been calculated for the period 1891-1935 (Figure 2), so this is the variable that has delimited the time horizon of the present study.

The central variable of the study is innovation in military technology. As an indicator of this variable, we have used military patents registered in the country. It is well known that patents have limitations as an indicator of innovation (they do not capture all innovations; they do not discriminate between more and less valuable inventions; many are not put into practice; etc.), but also advantages (relevant inventions are usually patented; they cover all sectors; they reflect an innovative effort even if they are not put into practice; patent data are available since the 19th century; etc.).

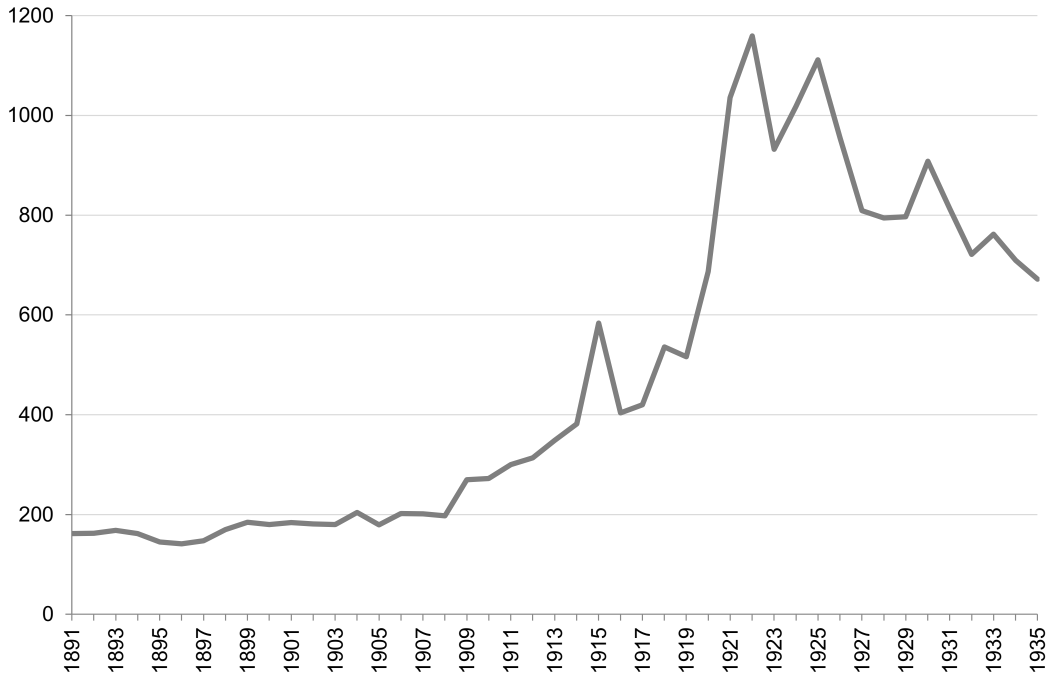

Figure 1. Spanish defense spending, 1891-1935 (million pesetas of 1995). *Sources*: Instituto de Estudios Fiscales (1976, 1979, 1982) and Carreras, Prados de la Escosura, and Rosés (2005).

Figure 2. Modernization index of the Spanish armed forces, 1891-1935 (1895 = 1). *Source*: Martos Gómez and Ortiz-Villajos (2022).

Although the debate on their validity has been extensive, they are generally accepted and used as a proxy indicator of innovative activity (Diebolt and Pellier 2020; Griliches 1990). Moreover, in our case and in the period analyzed there is, at present, no other indicator that allows us to analyze the innovation of the military industry as a whole. The same happens, for example, with the Spanish electrical industry, as Cayón García (2017) points out.

The source from which we obtained the information is the historical database of the Spanish Patent and Trademark Office, which includes patents registered in Spain between 1826 and 1966 in three successive stages, each with its specific database. The patents in this study come from the one corresponding to the period 1878-1940 (Sáiz et al. 2000-2008).

Although the contours of the military industry are not very clear, since there may be products of dual use (both civilian and military), here we have considered that the military industry is 'that which manufactures products of unequivocally military use, such as weapons, military vehicles, ammunition, etc., excluding those goods (food, clothing, lubricants, etc.) of predominantly civilian use' (García Alonso 1994, 67). To identify patents relating to this industry, we have been guided by the International Patent Classification (IPC), which consists of eight major sections (A to H), divided into classes, which in turn are divided into subclasses and these into groups (www.wipo.int/classifications). Even so, the identification of military patents is not automatic, because these patents are scattered among the various IPC classes and because there are military inventions that cannot always be detected from the IPC (Vicente Oliva 2019). There are classes that correspond to predominantly military technology, such as F41 (Weapons) and F42 (Ammunition; Blasting), and others of general technology that have some expressly military subclasses. Thus, for example, within Class B63 ('Ships or other waterborne vessels') there is subclass B63G ('Offensive or defensive arrangements on vessels…'), which includes patents of specifically military technology. We have included in the database only those classes, subclasses or groups of patents expressly relating to military armament or equipment. However, since in some cases the IPC designation is ambiguous, we have also been guided by the patent title in deciding whether to include it or not. In other words, in many cases we have followed a manual identification process.[7] Even so, we may have missed some patents for military use and we may have added some non-military ones, but these cases would represent a minimal percentage. In any case, the study excludes unpatented inventions kept secret, a frequent resource in the military industry,[8] so it does not cover all the technology generated.

In total, we have identified 6,044 patents related to the military industry between 1878 and 1939, representing 4.3% of the total number of applications and almost 9% of those in the manufacturing industry[9]: a not insignificant weight if compared to relevant sectors such as electricity or railways.[10] Its breakdown according to the main classes is shown in Table 1, which indicates a clear predominance of patents for weapons (F41), with more than half of the patents in the sector. They are followed by aircraft (B64) and ammunition and blasting (F42) patents, each with 20%; and vessel patents (B53), with 5.2%.

It is not the purpose of this paper to analyze in detail the characteristics and evolution of military patents, a task that we will address in another study. What is intended now is only to present the series to be used in the econometric analysis. For this study, we will use the total number of military patents, but also some more specific types, which are relevant for a deeper understanding of the relationships between our variables. Specifically, we have disaggregated patents in three ways:

Table 1. Military industry patents applied for in Spain, 1878-1939.

IPC class	Sector	No. of patents	%
B63	Vessels	314	5.2
B64	Aircraft	1,216	20.1
F41	Weapons of all types and their accessories*	3,299	54.6
F42	Ammunition and blasting	1,215	20.1
	Total	6,044	100.0

Source: Sáiz et al. (2000-2008). * Includes 29 patents of land vehicles and 6 miscellaneous (B60; B62).

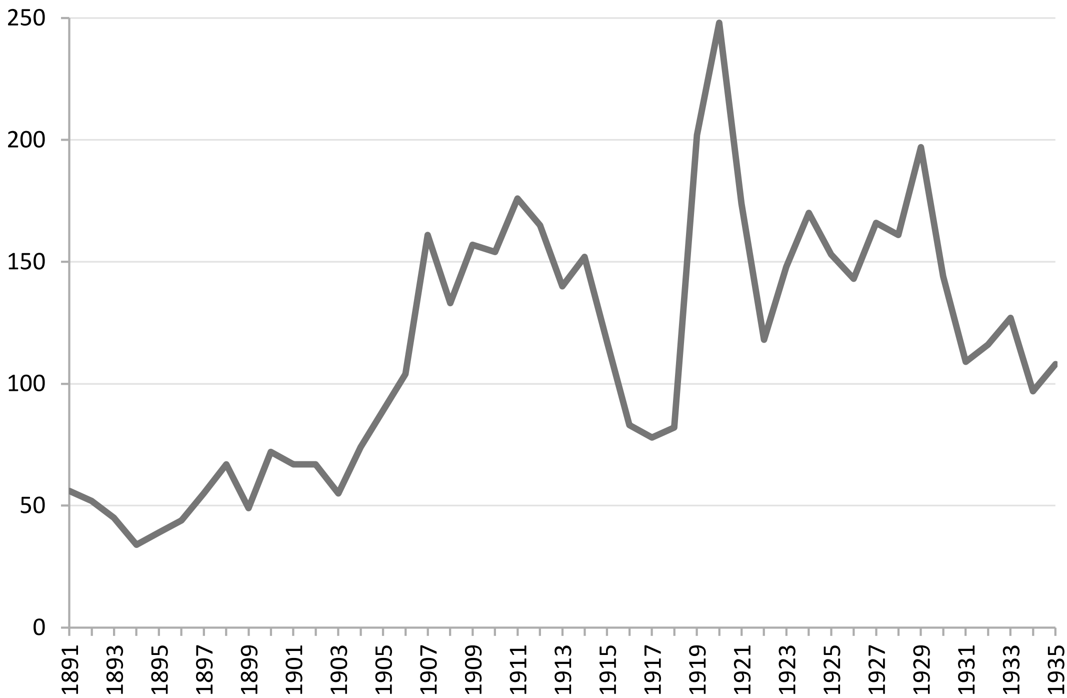

Figure 3. Military patents applied for in Spain, 1891-1935. *Source*: Sáiz et al. (2000-2008).

domestic versus foreign; individual or independent versus corporate; and high-value patents versus the rest.

Figure 3 shows the evolution of the total number of patents in the military industry. Broadly speaking, there was an upward trend until 1930 and a downward trend thereafter as a result of the economic depression. But in between there were some important fluctuations: an accelerated increase between 1903 and 1912; a sharp drop around World War I, because the belligerent countries reduced applications; and an expansive peak in the immediate post-war period due to the accumulation of foreign patents that had not been registered because of the extraordinary circumstances.

The military patents disaggregated between those applied for by residents and non-residents in the country are shown in Figure 4. The predominance of foreign patents was very clear throughout the study period. Overall, they accounted for approximately 70% compared to 30% of domestic patents. On the other hand, in the total number of applications in the country, foreign patents weighed considerably less, 56% (Sáiz 2005), which indicates the high technological dependence of the Spanish military industry, as is well known thanks to several studies (Díaz Morlán 2019; Gómez Mendoza 1988; Gómez Mendoza and López García 1992; Lozano Courtier 1997). This is not surprising, since this was generally the case in high-technology sectors at that time (Ortiz-Villajos 2002). It is true, however, that the weight of domestic military patents tended to increase over time, which could be interpreted as a reduction in this dependence, although certainly small. The data is also indicative that Spain was an interesting market for foreign military technologies, as we know – through an ongoing investigation– from the hundreds of arms purchase contracts made between the Spanish armed forces and dozens of foreign companies that registered patents in Spain.

As for the boom observed in the total number of military patents in the first decade of the 20th century (Figure 3), it can be deduced from Figure 4 that it was mainly due to those registered by non-residents. This fits with the weight that foreign technology had in the government initiatives of those years to stimulate the national military industry. This was the case with the plans for the

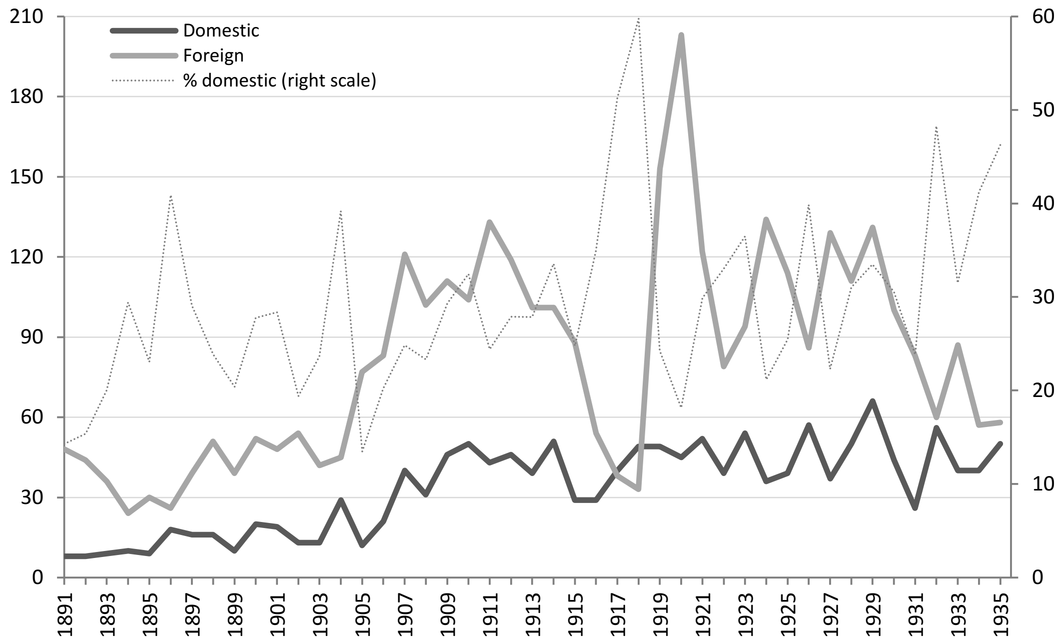

Figure 4. Military patents applied for by residents and foreigners, 1891-1935. *Source*: Sáiz et al. (2000-2008).

reconstruction of the squadron (Lozano Courtier 1997; Gómez Mendoza 1988), with the aeronautical industry (Gómez Mendoza and López García 1992) and with the acquisition of licenses for the production of cannons and other armament by the Ministry of War (Cardona 2004, 271). Be that as it may, foreign patents were dominant, but what is relevant is to contrast whether they had any significant differential effect against national ones.

Second, we have differentiated between military patents filed by individuals (independents) and by companies (Figure 5). In absolute numbers, both types were practically equal in the whole period, as was the case with electrical patents (Cayón García 2017, 27).[11] It can be seen, however, that individual patents were predominant until the beginning of the 20th century. From then on, corporate patents took the lead, although without distancing themselves very far at any time. That is to say, in the military sector, independent inventors maintained a notable importance, unlike in other high-tech sectors,[12] an aspect that will be interesting to investigate in the future. In any case, the reason for distinguishing between individual and corporate patents is that it might be thought that the latter, having greater economic backing, are more valuable in general than those applied for by individuals. This seems to follow from studies on the Italian and Spanish cases of the same period as ours (Cayón García 2017; Nuvolari and Vasta 2015; Sáiz 2012). However, this is not so clear in the cases of the United States, United Kingdom and Japan (Nicholas 2010, 2011b). That is, it is not so clear that corporate patents are by definition more valuable than those of independents.

Finally, we have also disaggregated military patents between those that were of high value (HVP) and the rest (Figure 6). Calculating the value of a patent is neither obvious nor straightforward. Therefore, various ways of doing so have been proposed, such as using the number of citations, assignments, or annual renewals of the patent.[13] The renewals method, perhaps the most widespread, was justified by Schankerman and Pakes (1986) with a model according to which the time that a patent remains in force would be that in which the discounted present value of the net returns of the patent is positive. Therefore, since each annuity entails an additional cost, the value of the patent would be proportional to the number of years it remains in force. Although there have been important (valuable) patents that have been short-lived for various reasons (MacLeod et al. 2003;

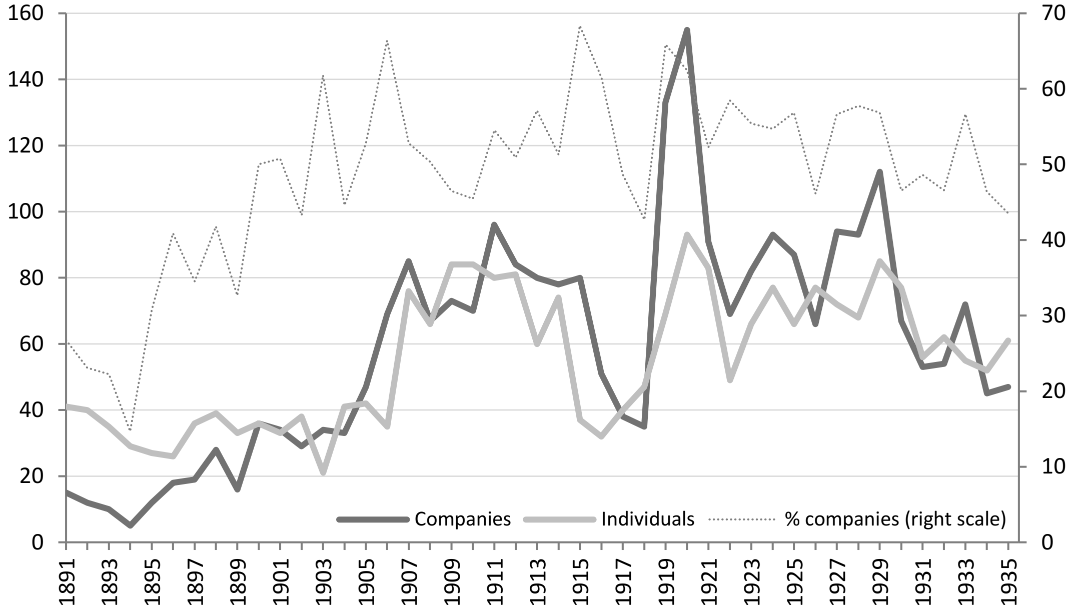

Figure 5. Military patents applied for by individuals and companies, 1891-1935. *Source*: Sáiz et al. (2000-2008).

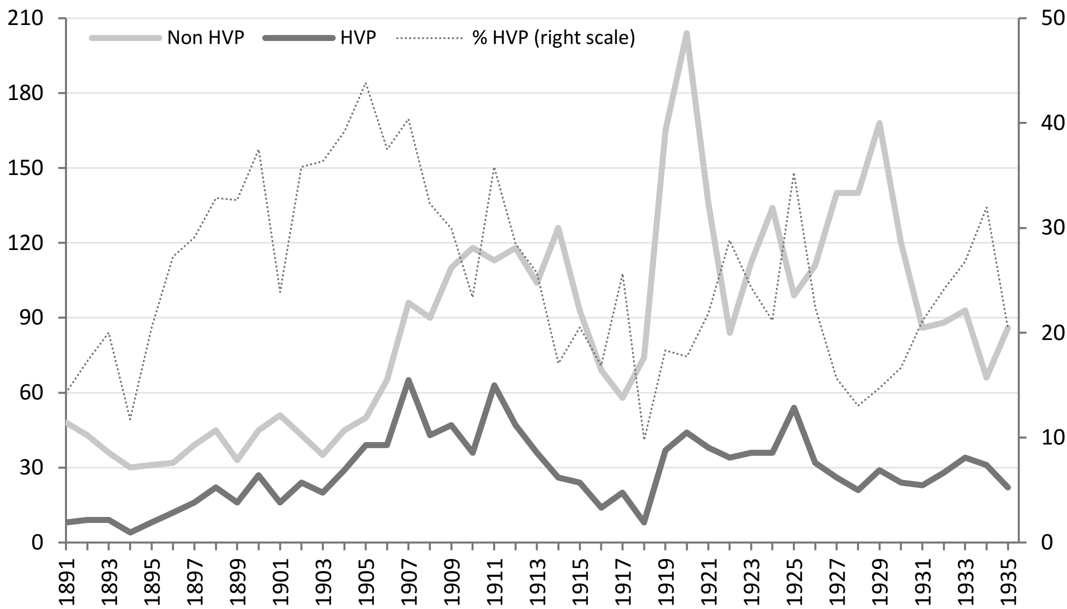

Figure 6. High-value (HVP) and non-high-value (Non HVP) military patents, 1891-1935. *Source*: Sáiz et al. (2000-2008).

Nicholas 2011a), this criterion has been useful in several historical studies (Brunt, Lerner, and Nicholas 2012; Streb, Baten, and Shuxi 2006).

In a paper on the United Kingdom, Nicholas (2011a, 326) qualifies as 'low value' patents those that expire before the first renewal fee is paid (in the third or fourth year of the application) and 'high value' patents those that remain in force until the end (14 years). As patent systems vary from period to period and from country to country, the valuation criteria have not been homogeneous. Thus, in his study on the Spanish case, where a patent could last up to 20 years, Cayón García (2017) has considered as 'high value' patents those that remained in force 10 years or more. This is the criterion that we have adopted, but with a variation: we have also included among high-value patents the 'patents of introduction' that were in force for the entire time allowed for them (5 years).[14] Figure 6 shows that among the military patents, those that were not of high value predominated, with 75% of the total against 25% of the HVPs. The graph shows, in turn, that the percentage of HVPs grew from the end of the 19th century to almost 45% in 1905, declining until the end of the Great War and growing again since then with some fluctuations, although no longer reaching the weight of the beginning of the century: another question that remains for future research. Having completed the description of the variables, we will now explain the model on which our analysis is based.

Model

As mentioned above, to find out whether military patents (Figures 3 to 6) had any relationship with defense spending (Figure 1) or with the modernization of the Spanish armed forces (Figure 2), we will use the vector autoregressive (VAR) technique, which extends the univariate autoregressive (AR) model to two or more variables. In the unrestricted VAR model, each variable has an equation that includes its own lags and those of the other variables in the model, forming a system of equations whose expression is as follows:

$$X_t = c + \sum_{i=1}^{p} \beta_i X_{t-i} + e_t \qquad [1]$$

where X_t is a vector (n x 1) of stationary variables, c is a vector (n x 1) of constants, e_t is a vector (n x 1) of random errors, called impulses, innovations or shocks, and p are the lags included in the model, which determine the order of the VAR(p). The coefficients of the variables (β_i) are estimated by OLS. This technique is useful when it is considered that the variables may be related to each other, but there is not adequate knowledge of the structure of this relationship, as is the case here. It serves to detect a possible causal relationship between variables in the Granger sense (i.e. not strictly speaking causality, but precedence), as well as to elucidate whether this relationship is unidirectional or bidirectional. In addition, it allows the calculation of impulse-response functions, which indicate the effect over time that a shock in one variable has on each of the variables of the model. In case there is cointegration between the variables, a VAR model with restrictions or error correction model (VECM) could be estimated to detect a possible long-term relationship between them.

As Table 2 shows, the Augmented Dickey-Fuller (ADF) and Pillips-Perron (PP) unit root tests indicate that all variables are non-stationary in levels, but stationary in first differences; that is, they are all integrated of order one: I(1). On the other hand, Johansen cointegration test indicates that there is no cointegration between our main variables, i.e. between military patents and defense spending on the one hand, and the modernization index and military patents on the other.[15] However, unit root and cointegration tests are not very reliable with small samples (Maddala and Kim 1998; Diebolt and Pellier 2020), such as ours (45 observations). In these cases, causality tests, which rely on unit root and cointegration properties, can have serious biases. Therefore, instead of estimating a standard VAR model with the variables in differences, we have resorted to the method proposed by Toda and Yamamoto (1995), which allows robust causal inferences in the Granger sense to be made from a VAR in levels, independently of the integration or cointegration properties of some or all of the variables in the system. Specifically, the method consists of artificially increasing the VAR by including as many additional lags of each variable as indicated by the maximum order of integration of the system variables. This guarantees the usual asymptotic distribution of the Wald statistic, so this test could be applied to the coefficient matrices up to the optimal lag order.[16] In other words, this method makes it possible to test Granger's hypothesis of non-causality by means of

Table 2. Unit root tests.

	ADF			PP		
Variable	Level (t-stat.)	1st difference (t-stat.)	Order of integration	Level (Adj. t-stat.)	1st difference (Adj. t-stat.)	Order of integration
DSPEND	−1.5947	−7.8225	I(1)	−1.5119	−7.8160	I(1)
MODIND	−1.4121	−8.6565	I(1)	−1.2306	−8.8661	I(1)
MILITPAT	−1.9897	−7.3442	I(1)	−1.9431	−7.3476	I(1)
DOMPAT	−1.6231	−9.7349	I(1)	−2.6042	−12.8000	I(1)
FORPAT	−2.2690	−7.6205	I(1)	−2.2690	−7.6855	I(1)
CORPAT	−2.1565	−7.0570	I(1)	−1.9182	−7.9417	I(1)
INDPAT	−2.5437	−7.9780	I(1)	−2.5473	−7.9780	I(1)
HVPAT	−2.8718	−9.0400	I(1)	−2.7895	−9.6944	I(1)
NHVPAT	−1.8526	−6.7833	I(1)	−2.1143	−8.7664	I(1)

ADF: H_0: Presence of unit root. PP: H_0: Presence of unit root. DSPEND: defense spending; MODIND: modernization index; MILITPAT: total military patents; DOMPAT: domestic patents; FORPAT: foreign patents; CORPAT: patents of firms; INDPAT: patents of independents; HVPAT: high-value patents; NHVPAT: non-high-value patents.

the Wald test, which provides a general approximation –taking into consideration all the lags as a whole– to the relationship between the variables.

The augmented VAR(p+d) model according to the method of Toda and Yamamoto (1995) would be formulated as follows:

$$X_t = c + \sum_{i=1}^{p} \beta_i X_{t-i} + \sum_{i=p+1}^{p+d} \beta_i X_{t-i} + e_t \quad [2]$$

where d is the maximum order of integration of the system variables. The other notations are the same as for the VAR(p) model in equation [1]. The modified Wald test requires that the maximum order of integration (d) does not exceed the optimal number of lags (p), a condition that is met in all our models. The usual diagnostic checks indicate that they also meet the assumptions of normality, autocorrelation and heteroscedasticity in the distribution of the residuals, except in the two models that distinguish between high- and low-value patents, where the normality assumption fails.

The results of the estimations are presented below, but first it is necessary to point out that the graphical representation of our variables (Figures 1 to 6) indicates the probable presence of outliers. Since these data can distort the results, we have proceeded to identify and intervene on them. For this purpose, we have used the TRAMO program (Time Series Regression with ARIMA Noise, Missing Observations, and Outliers) developed by Gómez and Maravall (1994, 1996), which is widely used in the analysis of time series, including patent series in the long term (Diebolt and Pellier 2020). In our case, such technique has confirmed the existence of some outliers both in the modernization index (1909, 1913 and 1915) and in defense spending (1915, 1921). They have also been identified in total military patents (1919), as well as in those applied for by foreigners (1919) and by companies (1894, 1899, 1919) and in high-value patents (1894, 1918), but not in those applied for by residents or by individuals, nor in those that were not of high value. The series requiring intervention have been linearized with the same TRAMO program.

Results

This section is divided into three parts. The first two contain the results of the modified Wald tests of Granger causality (Toda and Yamamoto 1995) between (1) military patents and defense spending and (2) military patents and modernization of the armed forces. The third shows the impulse-response functions of the estimated models.

Table 3. Modified Wald test for Granger causality between military patents and defense spending - VAR(p +d) in levels.

	Dependent variable	
Regressor	MILITPAT	DSPEND
MILITPAT	-	0.0018***
DSPEND	0.8447	-

Optimal lag (p) = 1; order of integration (d) = 1. Figures reflect the p-value of the χ^2 statistic. The null hypothesis is that the regressor does not causally affect the dependent variable. *, **, *** denote significance at 10%, 5% and 1% respectively.

Defense Spending and Military Patents

As indicated in the second section, some studies have found a positive influence of defense spending on innovation in military technology. To test whether this is true in our case, we have estimated a bivariate augmented VAR model, in which the variable to be explained is the total number of military patents applied for in Spain (MILITPAT) and the explanatory variable, total defense spending (DSPEND). According to the usual selection criteria –all coincident in this case– the optimal number of lags of the model is one,[17] as is the maximum order of integration (Table 2), so we have estimated a VAR(1 + 1) according to the expression [2]. The result of the causality test is reported in Table 3.

In this case, the test indicates that defense spending had no causal effect (in the Granger sense) on military patents, while the latter did have a causal effect on spending, at a significance level of 1%. This contradicts our initial hypothesis. However, it is a reasonable and illuminating result, since it indicates that, in the Spanish case, the generation of technology preceded the interest and effort of the military authorities to acquire it. This is logical since, in general terms, the armed forces purchased armament from specialized companies; and, although they also produced armament in some of their own factories, they normally did so under license.[18] In both cases, therefore, the filing of patents –the innovative activity– preceded military spending.

This result leads to take a further step in the analysis to find out whether the effect on military spending varied according to the origin, type of applicant and value of the patented technology, according to the disaggregations explained in the third section. To do so, we estimated the corresponding trivariate augmented VAR models according to expression [2], in which the dependent variable is defense spending (DSPEND) and the explanatory variables, military patents disaggregated between domestic (DOMPAT) and foreign (FORPAT) (model A), of individuals (INDPAT) and companies (CORPAT) (model B) and those that were of high value (HVPAT) versus those that were not (NHVPAT) (model C). The results of the causality analysis are shown in Table 4.

The result of model A shows first of all that defense spending was very significantly influenced by foreign patents, but not by domestic ones, which is not surprising given the clear predominance of the former in the country (Figure 4). This is also consistent with the historical evidence of the preferential recourse of the armed forces and the national military industry to foreign technology (Cubel 1994; Díaz Morlán 2019; Gómez Mendoza and López García 1992; López and González Gascón 2019). Second, military spending had no effect on either domestic or foreign patents, in line with what was observed for patents as a whole (Table 3). This is a logical result, since foreign patents – financed in any case with funds from their respective countries– were usually registered in Spain as part of a global protection strategy (Sáiz and Pretel 2014), and the Spanish armed forces hardly invested in technology creation.[19] The third piece of evidence is that, while foreign patents did not influence domestic ones, the latter did, and very significantly so, in foreign ones. One possible explanation is that indigenous technological development would have boosted the introduction of more advanced technologies from abroad, with the consequent entry of patents. This would be in

Table 4. Modified Wald test for Granger causality between defense spending and military patents by type - VAR(p+d) in levels.

Regressor	Dependent variable		
Model A	**DSPEND**	**DOMPAT**	**FORPAT**
DSPEND	-	0.5572	0.9599
DOMPAT	0.3894	-	0.0026***
FORPAT	0.0091***	0.7279	-
Model B	**DSPEND**	**INDPAT**	**CORPAT**
DSPEND	-	0.7395	0.8345
INDPAT	0.0745*	-	0.0469**
CORPAT	0.1929	0.2002	-
Model C	**DSPEND**	**HVPAT**	**NHVPAT**
DSPEND	-	0.4519	0.9830
HVPAT	0.4252	-	0.1872
NHVPAT	0.0391**	0.4127	-

Model A: optimal lag (p) = 1; integration order (d) = 1. Model B: optimal lag (p) = 1; integration order (d) = 1. Model C: optimal lag (p) = 2; integration order (d) = 1. The figures reflect the p-value of the χ^2 statistics. The null hypothesis is that the regressor does not causally affect the dependent variable. *, **, *** denote significance at 10%, 5% and 1% respectively.

line with the positive feedback between indigenous and imported technology observed at that time in Italy (Barbiellini Amidei, Cantwell, and Spadavecchia 2011) and Australia (Magee 1999) and, more recently, in various developing countries (Fu, Pietrobelli, and Soete 2011). Some cases suggest that this may also have happened in Spain,[20] although the subject would require a specific study.

Turning to model B, it can be seen that individual patents had a significant impact on defense spending, in contrast to corporate patents. This is a surprising result since, as we have seen (Figure 5), the two types were in equilibrium during the study period. In any case, this would indicate the relevance of independent patents at that time, in line with Nicholas (2010). Second, there is a significant influence (at 5%) of individuals' patents on corporate ones, but not the other way around. This could reflect the fact that the patents of independents would have boosted business innovation, either because they gave rise to companies that filed new patents or because their assignment helped licensee companies to innovate, or because the inventors were hired by them, as was happening in other countries (Lamoreaux and Sokoloff 2005). There are indications that all this was taking place in the Spanish military industry at the time,[21] although a detailed study will be necessary to assess the extent of this phenomenon.

As for model C, it is observed that spending was significantly influenced by patents that were not of high value and not by those that were. This is a paradoxical result, which goes against expectations, since it would indicate that the armed forces would have prioritized spending on low-quality technology. However, this result should be treated with caution, since the residuals of this model do not follow a normal distribution (p-value of the Jarque-Bera statistic = 0.0000). It is also conceivable that this result is a sign that with a dichotomous classification (high/low value), relevant information on the value of patents is lost. This is another point that requires further study.

Military Patents and Modernization of the Armed Forces

In the case of the relationship between military technology and modernization of the armed forces, what we expect to find according to the literature (cf. second section) is an influence of patents on modernization. To this end, we have estimated an augmented VAR model in levels according to the expression [2], with the modernization index (MODIND) as the dependent variable and total military patents (MILITPAT) as the explanatory variable. According to the usual selection criteria, the optimal number of lags to include would be two,[22] so a VAR(2 + 1) was estimated. The causality test (Table 5) yields the expected result, i.e. that military patents registered in Spain had a significant influence on the modernization of the armed forces, while modernization had no causal effect on patents. It is, therefore, a unidirectional relationship.

In a second step, we have proceeded to contrast whether the different types of patents –national and foreign; of individuals and firms; of high value and the rest– had a differential relationship with the modernization of the armed forces. To do so, we estimated the corresponding trivariate augmented VAR models according to expression [2]. The results of the causality analysis are reported in Table 6.

Starting with model A, it can be seen that the modernization of the armed forces was influenced by foreign patents, but not by domestic ones. This is consistent with the available evidence on the special relevance that the incorporation of foreign weaponry in the Spanish Army and Navy had in that period.[23] Although less clearly (at 10% significance), a relationship in the opposite direction is also observed; that is, it seems that an advance in modernization would have influenced the application for foreign patents. We would therefore be in the presence of a bidirectional relationship between foreign patents and the modernization index. It is surprising, on the other hand, that the test does not detect a relationship between national and foreign patents when in a previous model (Table 4) it was very significant. The impulse-response analysis will clarify this point.

Turning to model B, we observe, first, that modernization was not influenced by either independent or corporate patents. Although this surprising result will be qualified by the impulse-response

Table 5. Modified Wald test of Granger causality between modernization and military patents - VAR(p+d) in levels.

	Dependent variable	
Regressor	MODIND	MILITPAT
MODIND	-	0.1143
MILITPAT	0.0649*	-

Optimal lag (p) = 2; order of integration (d) = 1. Figures reflect the p-value of the χ^2 statistic. The null hypothesis is that the regressor does not causally affect the dependent variable. *, **, *** denote significance at 10%, 5% and 1% respectively.

Table 6. Modified Wald test of Granger causality between modernization and military patents by type - VAR(p+d) in levels.

Regressor	Dependent variable		
Model A	**MODIND**	**DOMPAT**	**FORPAT**
MODIND	-	0.1024	0.0626*
DOMPAT	0.1460	-	0.1973
FORPAT	0.0160**	0.1291	-
Model B	**MODIND**	**INDPAT**	**CORPAT**
MODIND	-	0.0347**	0.0044***
INDPAT	0.8714	-	0.0846*
CORPAT	0.2537	0.1829	-
Model C	**MODIND**	**HVPAT**	**NHVPAT**
MODIND	-	0.2719	0.9941
HVPAT	0.8603	-	0.2909
NHVPAT	0.0009***	0.2888	-

Model A: optimal lag (p) = 5; integration order (d) = 1. Model B: optimal lag (p) = 6; integration order (d) = 1. Model C: optimal lag (p) = 2; integration order (d) = 1. The figures reflect the p-value of the χ^2 statistics. The null hypothesis is that the regressor does not causally affect the dependent variable. *, **, *** denote significance at 10%, 5% and 1% respectively.

analysis, it could be inferred from it that it was the combination of patents by firms and individuals that was effective. The cases noted above (footnote 21) of successful collaboration between independent inventors and companies would be an indication of this. In any case, this is a hypothesis that requires further study. On the other hand, what we do observe is a clear influence of modernization on the two types of patents. Although –as in the case of foreign patents (model A)– we did not expect to find a relationship in the inverse direction, since it does not occur for all patents (Table 5), it is not without logic that military modernization had an effect on the registration of patents in the sector. We will return to this when analyzing the impulse-response functions. Finally, we see an influence of individual patents on corporate ones, as also detected by a previous model (Table 4).

Finally, model C indicates that only patents that were not of high value had a significant impact on the modernization of the armed forces. This is a paradoxical result, but also not very reliable, since the residuals of the model are not normally distributed (p-value of the Jarque-Bera statistic = 0.0000), as we have seen to be the case when the dependent variable is expenditure (Table 4). In any case, the result invites reflection and research on the valuation of patents as a function of the time they remain in force.

Impulse-Response Analysis

The impulse-response functions now presented seek to test the reaction over time of each variable to a shock or one-time increase (also called innovation in VAR jargon) in the other variables,[24] taking into account all the relationships in the system. As in the previous sections, we first analyze the relationship between defense spending and military patents and, secondly, between the latter and modernization. In both cases, the analysis is done for all patents and for their disaggregation between domestic and foreign and individual and corporate ones.[25] The impulse-response functions provide aspects not captured by the Wald/Granger tests, such as the sign of the effect, while serving as a robustness check of the results of these tests.

Starting with the relationship between defense spending and total military patents, the impulse-response between the two variables (Figure 7) reaffirms the results of the Wald test (Table 3). Indeed, the graph shows that a shock in defense spending has no appreciable influence on the number of patents over time. On the other hand, a shock in the number of patents filed has a noticeable effect on spending, which is positive from the year following the shock, grows until the fourth year and then begins a slight decline, but remains high. It is therefore a persistent effect, although it is only significant until the fourth year.

Figure 8 shows the impulse-response functions between defense spending and military patents disaggregated between domestic and foreign. Looking first at the expenditure response

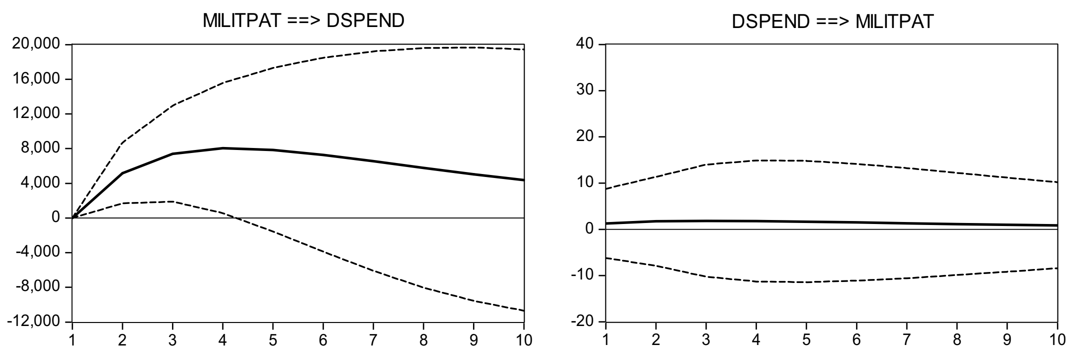

Figure 7. Impulse-response functions: defense spending (DSPEND) and military patents (MILITPAT).

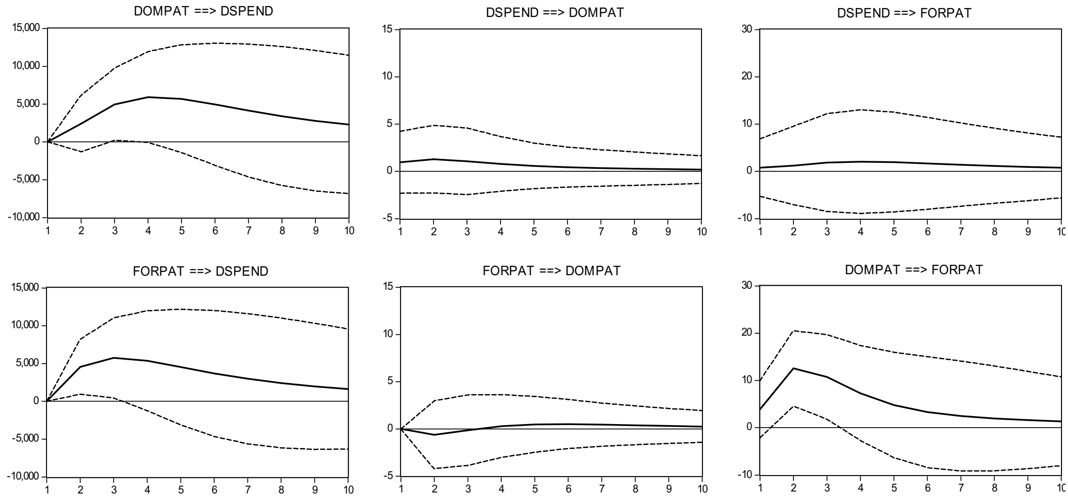

Figure 8. Impulse-response functions: defense spending (DSPEND), domestic patents (DOMPAT) and foreign patents (FORPAT).

(first column), it is observed that a shock in foreign patents has a positive effect, significant from the beginning to the third year. This confirms the special relevance of foreign technology for the Spanish military effort detected by the causality test (Table 4). Second, a positive effect of domestic patents on spending is also observed, although significant between the third and fourth year. The fact that the effect occurs with this lag may explain why the Wald test did not find this relationship to be significant (Table 4). The impulse-response function thus provides a valuable and reasonable insight, since we also have evidence of indigenous patents on which the Spanish military relied.[26]

As for domestic patents (second column), they were not significantly affected either by a shock in spending or in foreign patents, thus confirming the result of the Wald test (Table 4) and reinforcing the idea that defense spending in Spain followed technology generation. Finally, the reaction of foreign patents (third column) was nil to an increase in defense spending, but positive and significant to a shock in domestic patents, notably in the second year, but observable until the fourth year. This is fully in line with the results of the causality test (Table 4) and reaffirms the above idea of the contribution of indigenous technological development to the attraction of foreign technology.

The impulse-response functions between defense spending and patents of independents and firms (Figure 9) show only two significant and positive reactions: those of defense spending and corporate patents to a shock in patents of individuals. This is consistent with the results of the Wald test (Table 4), so we refer to the comments made above in this regard.

Turning to the impulse-response functions between total patents and the modernization index (Figure 10), the first thing they show is that a shock in patents boosts modernization. The effect is zero in the first year, very noticeable in the second year and, after a slight decline, is maintained in the following years, although it is only significant until the second year. This is consistent with the results of the causality test (Table 5). Second, it is observed that modernization had a negative effect on military patents, although only significant in the second year. This result, not detected by the Wald test (Table 5), is initially surprising. One possible explanation would be that, following an advance in modernization, the armed forces would decrease their investment in technology and, therefore, patent registration would temporarily deflate. This is, however, a hypothesis that remains to be tested.

Figure 11 shows the impulse-response functions between the modernization index and military patents disaggregated according to their origin, domestic or foreign. First, it is observed that the

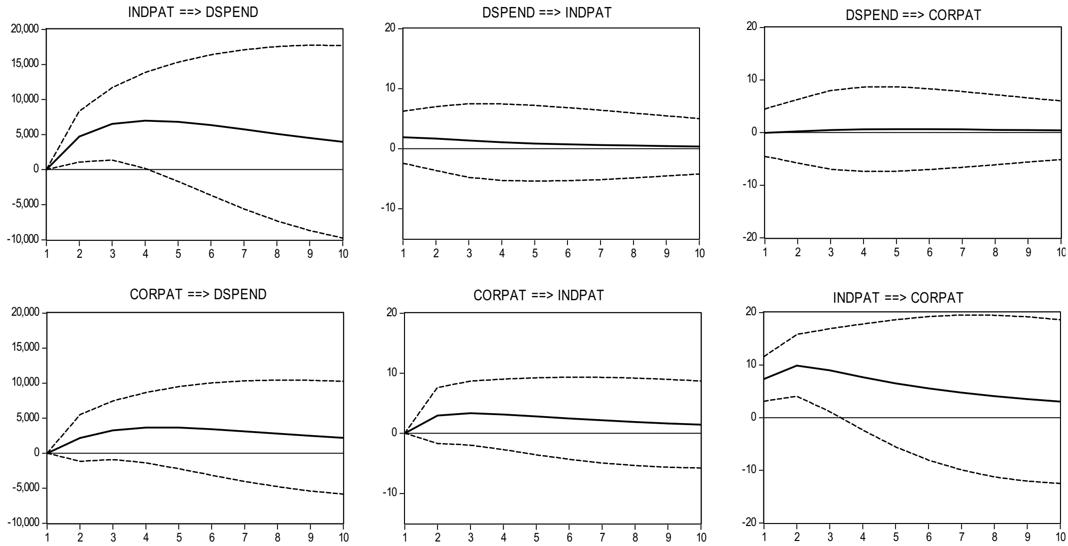

Figure 9. Impulse-response functions: defense spending (DSPEND), patents of individuals (INDPAT) and corporate patents (CORPAT).

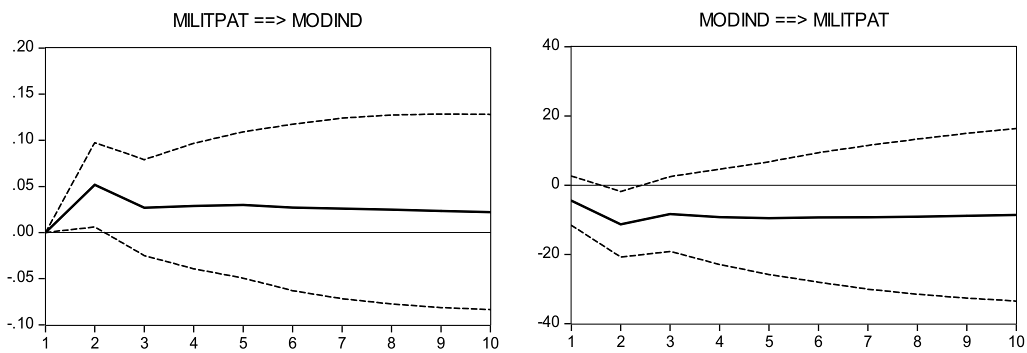

Figure 10. Impulse-response functions: modernization index (MODIND) and military patents (MILITPAT).

modernization index is positively and significantly affected by a shock in foreign patents, but only in the year following the impulse. We also observe a positive and significant response of the index to a shock in domestic patents, but only in the fifth year. The Granger test (Table 6) detects the first effect, but not the second, which could be explained by the fact that it occurs with such a delay. In any case, the impulse-response analysis confirms the special contribution of foreign technology to the modernization of the Spanish armed forces. Second, national patents were not affected by modernization, but were affected by foreign patents in the third and sixth years of the shock. The causality test (Table 6) detects no relationship in either of these two cases. The discrepancy can be explained by the late occurrence of the effect, apart from the fact that it is at the limit of significance. Third, the graph shows that foreign patents were positively and significantly affected by domestic patents in the following year of the shock. Thus, although the Wald test did not detect this effect (Table 6), the impulse-response function reinforces the evidence that domestic patents boosted foreign ones, as is clear from the model in which the dependent variable is defense spending (Table 4 and Figure 8). On the other hand, the impulse-response function does not detect that modernization had an effect on foreign patents, contrary to the Granger test (Table 6). The discrepancy may be due

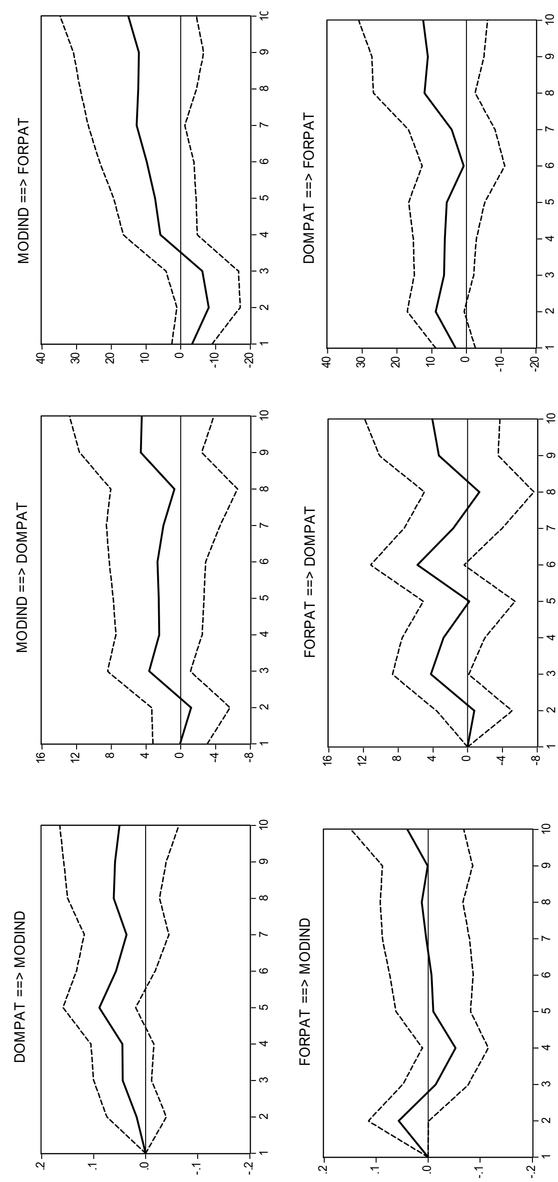

Figure 11. Impulse-response functions: modernization index (MODIND), domestic patents (DOMPAT) and foreign patents (FORPAT).

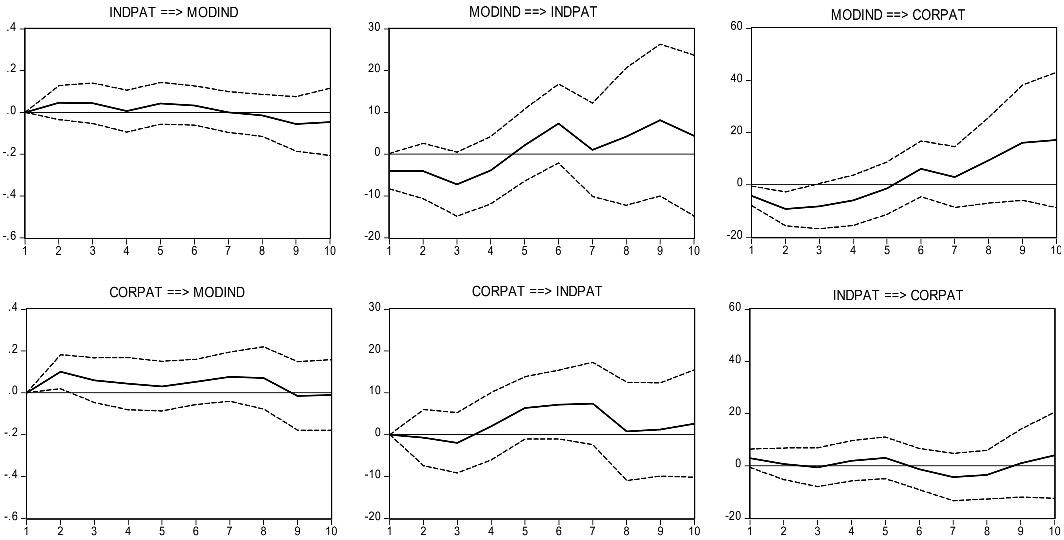

Figure 12. Impulse-response functions: modernization index (MODIND), patents of individuals (INDPAT) and patents of firms (CORPAT).

to the fact that, according to this test, the effect is of low significance (at 10%) and almost significant, in the second year, according to the impulse-response function. In any case, the effect would be negative as it was for the total number of patents (Figure 10).

Finally, Figure 12 shows the impulse-response between modernization and military patents applied for by individuals and companies. The functions detect a negative influence of modernization on corporate patents, significant in the first three years, and on independent patents, significant in the first and third years. In both cases, the effect becomes positive, although not significant, after the fifth year. Thirdly, there is a positive effect of independent patents on business patents, but only significant in the first year. All three results are consistent with those of the Wald test (Table 6). Finally, the graph shows a positive effect of corporate patents on the modernization index between the second and the eighth year, but only significant in the first two years. As we have seen, the Granger test detects no relationship between these variables (Table 6), which is at least put in doubt by the impulse-response function, which opens the way to think that corporate patents could have a positive effect on modernization. This would give them a certain added value compared to those applied for by independents, in line with the findings of Sáiz (2012). In any case, the subject requires further research.

Conclusions

It is widely accepted that the modernization of the armed forces depends to a large extent on innovation in military technology and that this has long been closely linked to countries' defense spending. However, there are hardly any studies that have analyzed these relationships with a quantitative approach. One of the reasons for this is the scarcity of statistical data available on innovation in military technology. This study makes a contribution in this sense with the construction of the historical series of military patents applied for in Spain from the end of the 19th century until the Civil War. This has made it possible to carry out a VAR analysis to elucidate whether innovation in military technology –as a whole and disaggregated in various ways– has been related to defense spending and to the modernization of the country's armed forces.

With respect to the relationship between defense spending and military technology, no effect of the former on the latter has been detected, as other studies have shown (Hall and James 2009;

Schmid 2018a), but the reverse is true. This result would indicate that technology generation precedes spending, which is actually consistent with the Spanish military's practice of acquiring already developed weaponry rather than financing its creation. In turn, this is somewhat consistent with what Evangelista (1988) noted for a non-centralized economy. When disaggregating patents between domestic and foreign ones, it is observed that those that most clearly affect defense spending are foreign ones, which is consistent with the predominant use of foreign weaponry by the Spanish armed forces. When the division is between patents of individuals and companies, it is observed that only those of individuals have a significant impact on spending, which is indicative of the relevance that independent inventors had in the sector at that time. Finally, it is also observed that high-value patents did not have a significant impact on spending, in contrast to those that were not. This is a paradoxical result, although not very reliable because the model does not meet the assumption of normality.

As for the relationship between military technology and modernization of the armed forces, the estimate indicates a positive influence of the former on the latter, in line with López-Rodríguez (2019) and other studies on military innovation (Cheung 2021). In the impulse-response analysis, an influence of modernization on patents has also been detected, albeit negative, which would indicate that, after a modernization effort, the military would decrease the demand for new technology in the short term. When going into more detail, it is observed that, among domestic and foreign patents, only the latter had a significant effect on modernization, which confirms the relevance that foreign technology had in the modernization of the Spanish armed forces. On the other hand, independent patents did not influence modernization, but corporate patents did according to the impulse-response function, which would indicate the greater effectiveness of these patents. Finally, the analysis shows that high-value patents had no effect on modernization, but non-high-value patents did. The normality criterion for the residuals is also not met in this model, making this result unreliable. This may be due to the loss of information resulting from a dichotomous classification of patent value.

This first approximation to the data confirms the close relationship between the variables analyzed. A more detailed analysis will make it possible to go deeper into aspects of this relationship that have only been hinted at. Although the research refers to a case from the past, it may have some useful implications for the present. For example, if defense spending does not determine the generation of technology but the other way around, keeping abreast of technological advances is crucial for the armed forces to optimize the use of ever scarce resources. It can also be learned that, if dependence on foreign armaments is inevitable, the strategic risk this entails can be mitigated by diversifying the geographical origin of technology, as Spain did in the period under analysis. In any case, the clear influence that national patents had on foreign patents shows that achieving a certain level of indigenous technological capacity is necessary to be able to absorb imported technology.

Issues that remain for future work are: a specific and more nuanced study of the value of patents; research on the relationship between independent and corporate patents, as well as on their relative effectiveness; the calculation of a military modernization index that includes other aspects besides equipment; and broadening the time and geographic horizon of the analysis to verify whether the observed behaviors are exclusive to the case studied or common to other countries and periods.

Notes

1. There are, however, numerous quantitative studies on the contribution of military R&D spending to civilian technological development (Acosta, Coronado, and Marín 2011; Acosta et al. 2013; Moretti, Steinwender, and Van Reenen 2021; Mowery 2010; Ruttan 2006; Schmid 2018b) and, most prominently, on the relationship between defense spending and economic development (Abu-Bader and Abu-Qarn 2003; Benoit 1973; Broude, Deger, and Sen 2013; Dritsakis 2004; Dunne, Smith, and Willenbockel 2005; Dunne and Nikolaidou, 2012; Dunne and Smith 2020; Kollias, Manolas, and Paleologou 2004; Ram 1995). There has also been extensive research on the determinants of defense spending (Alonso Neira and Martínez González 2008).

2. Military spending data for many countries are available from the 19th century to the present day. The Correlates of War Project (correlatesofwar.org) (cf. Singer 1987) contains data from 1816 to 2016, and the Stockholm International Peace Research Institute (SIPRI) (sipri.org), from 1949 to 2020.
3. It has been done on other issues, such as the effect of defense spending on the profitability of supply companies (Fonfría and Correa-burrows 2010).
4. Some studies have used military patents as a measure of innovation in the sector, but for short and recent periods. For example, Álvarez and Fonfría (2000) have quantified the patenting activity of the Spanish defense industry between 1987 and 1997 and Vicente Oliva (2019), for the period 2008-2018. The only study with patent data for the sector in the past (1830-1940) is Calvó (1997), but it is limited to the arms industry and has a descriptive approach.
5. As an exception, it is worth noting the study by Hoffman (2012), who, to contrast his 'tournament model', does provide some quantitative evidence of a positive relationship between military productivity and improvement in gunpowder technology in the Early Modern Age.
6. Both contemporary observers and historians point to the scarce material endowment as the main evidence of the backwardness of the Spanish armed forces (Cardona 1988; Sabaté Domingo 2016). For the treatises on military strategy of the time, the three decisive factors in warfare were: the instruction of the soldier, strategy and equipment (San Román 1999, 90).
7. Faced with the ambiguities of the IPC, the Derwent Innovations Index has a more refined classification system, which makes it possible to clearly identify military patents (Schmid 2018b, 2022). But that database, apart from the fact that it does not include all patents, is limited to the period after 1980, so it is not an option for us. In historical studies, recourse to IPC has been common for the sectoral classification of patents (Cayón García 2017; Vasta 1999).
8. We do not know the weight of these inventions. In addition, there were patents that were kept secret for national security or other reasons, but this was very exceptional in Spain at the time of our study (Ortiz-Villajos 1999, 251). Currently, it is estimated that in Spain and the United Kingdom there may be between 15 and 17 secret patents for every 10,000 applications (Acosta et al. 2013, 8).
9. In the same period, some 141,000 patents were applied for in Spain, of which 1.6% corresponded to the Agriculture and livestock sector; 7.9% to Mining and energy; 48.9% to Industry; 8.8% to Transport and communications; 3.3% to the Construction sector; and 11.9% to the Services sector (Sáiz 2005).
10. Electricity and communication patents accounted for 8% of the total in the same period (1878-1939) (Cayón García 2017, 20), and railway patents accounted for 2.7% of those registered between 1826 and 1936 (Cayón García et al. 1998, 11).
11. In the total number of applications in the country, independents predominated with approximately 70% of the total. However, corporate patents went from representing around 10% in the 1880s to 40% in the 1930s (Ortiz-Villajos 1999, 148; Sáiz 2012, 354), although without becoming predominant as they were in high-tech sectors such as the military or electricity. The growing weight of corporate patents in that period was a phenomenon common to many countries. In the United States, the United Kingdom and Japan, they went from representing around 10% of the total in 1880 to around 50% in 1930 (Nicholas 2011b).
12. For example, in the electricity sector, the weight of independent patents declined drastically after World War I (Cayón García 2017, Figure 3).
13. Bibliographic indicators, constructed from references to inventions or inventors in relevant publications, have also been used (Khan 2018; Nuvolari and Tartari 2011; Nuvolari, Tartari, and Tranchero 2021). A summary of the different proposals and authors can be obtained in Cayón García (2017, 16-19).
14. This was established in the laws of 1878 and 1902. On patents of introduction and their relevance in the Spanish patent system, see Sáiz (2014).
15. We have also applied the test to the six trivariate models resulting from disaggregating military patents into the various types described in the second section. In three of them, both the Trace and Max-Eigenvalue tests indicate no cointegration, but in three others, one test is positive and the other negative, so the result is inconclusive (for reasons of space, the Johansen test results are not shown, but are available upon request).
16. The additional lags are not explicitly considered in the Wald test, but they are necessary to ensure that the distribution of the test statistic asymptotically approximates the χ^2 distribution.
17. Determination of the optimal lag of the VAR model (MILITPAT-DSPEND).

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-202.0558	NA	72.1111	9.9539	10.0375	9.9843
1	-146.1539	103.6231*	5.7368*	7.4221*	7.6729*	7.5134*
2	-145.0455	1.9464	6.6185	7.5631	7.9811	7.7153

* Indicates the optimum lag. LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

18. There is much evidence of the acquisition of licenses for military factories; for example, for the manufacture of naval artillery at the Trubia factory (Álvarez Laita 2008, 78), of Hotchkiss machine guns at the Oviedo factory (Calvó 1978, 65), of Schneider cannons at the Seville factory (Cardona 2004, 271) or of Wolff gunpowder at the Granada factory (Memorial de Artillería 1844-1936, Volume III, 35-36).
19. For this period we only have evidence of five patents registered by military factories, and all of them at the end of the period: four from the *Fábrica de Armas de Oviedo* (Oviedo Arms Factory) between 1929 and 1931 and one from the *Fábrica Nacional de Toledo* (Toledo National Factory) in 1935 (Sáiz et al. 2000-2008).
20. It is clearly seen, for example, in the beginnings of the aeronautics industry (Gómez Mendoza and López García 1992) and of the production of internal combustion engines (Ortiz-Villajos 2014).
21. For example, Juan Esperanza and Pedro Unceta, arms manufacturers and inventors, created in 1908 in the city of Éibar (Guipúzcoa) the company *Esperanza y Unceta*, which in turn registered its own patents and hired the services of Pedro Careaga, a well-known armament inventor. Jorge Loring, inventor and owner of several patents in aeronautical technology, was hired in 1917 by the Barcelona company *Talleres Hereter*, which also registered several patents. The engineer Leonardo Torres Quevedo invented in 1905 an airship whose patent he assigned to the French company Astra, which in 1911 began to produce the Astra-Torres airships. In addition, in 1906 he created with other partners the *Sociedad de Estudios y Obras de Ingeniería*, which also obtained patents. The military engineer Eduardo Barrón, a pioneer of aviation in Spain, designed and patented his own models and was hired in 1917 as head of the aviation section of *La Hispano*, which also registered patents (Sáiz et al. 2000-2008; *Diccionario Biográfico Español*; Wikipedia).
22. The SC criterion suggests a single lag, but all the others (AIC, HQ, LR and FPE) suggest two, so we have opted for this option.
23. The Navy was modernized, above all, with English technology (Lozano Courtier 1997), and the Air Force, with English, German, and French technology (Gómez Mendoza and López García 1992). The first armored units of the Army were created in 1919 with French Renault FT-17 tanks (Marín and Mata 2010, 23-24). There is even news that the military commanders rejected the acquisition of the rights to a national patent because they considered that the foreign ones were superior (*Memorial de Artillería* 1914, Vol. V, 742).
24. Specifically, a shock is a one standard deviation increase of the error term (e_t) of the equations of expression [2].
25. We do not include the breakdown between high and low value patents for reasons of conciseness. The result – which in this case is fully consistent with that of the causality analysis– is available upon request.
26. Such was the case, for example, of the Campo-Giro pistol, manufactured in Éibar by the company *Esperanza y Unceta*, which was declared regulatory for the Spanish Army in 1912 (Goñi Mendizabal 2007, 395). There are also some cases of military inventors, such as Isaac Peral, José González Ontoria, José Luis Díez or Joaquín Bustamente (Rodríguez González 2013, 13), in whose patents the Army or the Navy was interested

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

José M. Ortiz-Villajos http://orcid.org/0000-0002-7135-7221
José J. Martos-Gómez http://orcid.org/0000-0001-6004-197X

References

Abu-Bader, S., and A. S. Abu-Qarn. 2003. "Government Expenditures, Military Spending and Economic Growth: Causality Evidence from Egypt, Israel, and Syria." *Journal of Policy Modeling* 25 (6–7): 567–583. doi:10.1016/S0161-8938(03)00057-7.

Acosta, M., D. Coronado, and R. Marín. 2011. "Potential Dual-Use of Military Technology: Does Citing Patents Shed Light on This Process." *Defence and Peace Economics* 22 (3): 335–349. doi:10.1080/10242694.2010.491681.

Acosta, M., D. Coronado, R. Marín, and P. Prats. 2013. "Factors Affecting the Diffusion of Patented Military Technology in the Field of Weapons and Ammunition." *Scientometrics* 94 (1): 1–22. doi:10.1007/s11192-012-0857-8.

Alonso Neira, M. Á., and A. Martínez González. 2008. "Los determinantes del gasto en defensa en la literatura académica de los últimos cincuenta años: una revisión de las principales aportaciones y modelos." *Hacienda Pública Española/Revista de Economía Pública* 187: 109–137.

Álvarez, I., and A. Fonfría. 2000. "Estructura e innovación en la industria de defensa española." *Economistas* 85 (XVIII): 102–121.

Álvarez Laita, F. J. 2008. “Implicaciones industriales del Plan de Escuadra Maura-Ferrándiz.” *Cuadernos Monográficos del Instituto de Historia y Cultura Naval* 57: 65–86.
Barbiellini Amidei, F., J. Cantwell, and A. Spadavecchia 2011. Innovation and Foreign Technology in Italy, 1861-2011. *Quaderni di Storia Económica (Economic History Working Papers)*, 7 Banca d’Italia. 10.2139/ssrn.2233841
Bellais, R. 2013. “Technology and the Defense Industry: Real Threats, Bad Habits, or New (Market) Opportunities?” *Journal of Innovation Economics & Management* n°12 (2): 59–78. doi:10.3917/jie.012.0059.
Benoit, E. 1973. *Defence and Economic Growth in Developing Countries*. Boston: Lexington Books.
Bitzinger, R. A. 2021. “Military-Technological Innovation in Small States: The Cases of Israel and Singapore.” *Journal of Strategic Studies* 44 (6): 873–900. doi:10.1080/01402390.2021.1947252.
Bitzinger, R. A., and M. Raska. 2015. “Capacity for Innovation: Technological Drivers of China’s Future Military Modernization.” In *The Chinese People’s Liberation Army in 2025*, edited by R. Kamphausen and D. Lai, 129–161. Strategic Studies Institute: US Army War College Press.
Blanken, L. J., and J. J. Lepore. 2011. “Slowing Down to Keep the Lead in Military Technology.” *Defence and Peace Economics* 22 (3): 317–334. doi:10.1080/10242694.2010.491675.
Broude, M., S. Deger, and S. Sen. 2013. “Defence, Innovation and Development: The Case of Israel.” *Journal of Innovation Economics & Management* n°12 (2): 37–57. doi:10.3917/jie.012.0037.
Brunt, L., J. Lerner, and T. Nicholas. 2012. “Inducement Prizes and Innovation.” *The Journal of Industrial Economics* 60 (4): 657–696. doi:10.1111/joie.12002.
Calvó, J. L. 1978. “La ametralladora y su uso en España.” *Tiempo de historia* 38 (IV): 60–65.
Calvó, J. L. 1997. *La Industria Armera Nacional 1830-1940. Fábricas, Privilegios, Patentes y Marcas*. Éibar: Ayuntamiento de Éibar.
Cardona, G. 1988. “La política militar de la II República.” *Historia contemporánea* 1: 33–46.
Cardona, G. 2004. “El desastre del 98 y militarismo.” In *La crisis de fin de siglo en la provincia de Almería: el desastre del 98*, edited by C. R. Fuentes and R. M. Ú. Vilches, 267–277. Almería: Instituto de Estudios Almerienses.
Carreras, A., L. Prados de la Escosura, and J. Rosés. 2005. “Renta y riqueza.” In *Estadísticas históricas de España, siglos XIX-XX*, edited by A. Carreras and X. Tafunell, 1297–1376. Bilbao: Fundación BBVA.
Carreras, A., and X. Tafunell. 2021. *Between Empire and Globalization. An Economic History of Modern Spain*. London: Palgrave Macmillan.
Cayón García, F. 2017. “Invención y transferencia de tecnología en un país periférico: España, 1878-1939.” *Revista de historia industrial* 70 (XXVI): 15–44.
Cayón García, F., E. Frax Rosales, M. J. Matilla Quiza, M. Muñoz Rubio, and J. P. Sáiz González. 1998. *Vías paralelas. Invención y ferrocarril en España, 1826-1936*. Madrid: Fundación de los Ferrocarriles Españoles.
Cheung, T. M. 2021. “A Conceptual Framework of Defence Innovation.” *Journal of Strategic Studies* 44 (6): 775–801. doi:10.1080/01402390.2021.1939689.
Cubel, A. 1994. “Los efectos del gasto del estado en la industria de construcción naval militar en España 1887-1936.” *Revista de historia industrial* 5: 93–120.
Díaz Morlán, P. 2019. “Horacio Echevarrieta y los intereses alemanes en España en el período de entreguerras.” In *Pioneros. Empresas y empresarios en el primer tercio del siglo XX en España*, edited by R. Molina Recio, 233–262. Granada: Comares Historia.
Diebolt, C., and K. Pellier. 2020. “Patents in the Long Run: Theory, History, and Statistics.” In *History & Mathematics: Investigating Past and Future*, edited by L. E. Grinin and A. V. Korotayev, 80–119. Volgograd: ‘Uchitel’ Publishing House.
Dritsakis, N. 2004. “Defense Spending and Economic Growth: An Empirical Investigation for Greece and Turkey.” *Journal of Policy Modeling* 26 (2): 249–264. doi:10.1016/j.jpolmod.2004.03.011.
Duffy, M., edited by. 1980. *The Military Revolution and the State, 1500–1800*. Exeter: University of Exeter.
Dunne, J. P. 1995. “The Defense Industrial Base.” In *Handbook of Defense Economics*, edited by H. Keith and S. Todd, 399–430. Vol. 1. Amsterdam and New York: Elsevier.
Dunne, J. P., and E. Nikolaidou. 2012. “Defence Spending and Economic Growth in the EU15.” *Defence and Peace Economics* 23 (6): 537–548. doi:10.1080/10242694.2012.663575.
Dunne, J. P., and R. P. Smith. 2020. “Military Expenditure, Investment and Growth.” *Defence and Peace Economics* 31 (6): 601–614. doi:10.1080/10242694.2019.1636182.
Dunne, J. P., R. P. Smith, and D. Willenbockel. 2005. “Models of Military Expenditure and Growth: A Critical Review.” *Defence and Peace Economics* 16 (6): 449–461. doi:10.1080/10242690500167791.
Eloranta, J. 2007. “From the Great Illusion to the Great War: Military Spending Behaviour of the Great Powers, 1870-1913.” *European Review of Economic History* 11 (2): 255–283. doi:10.1017/S1361491607001979.
Eloranta, J. 2019. “Cliometric Approaches to War.” In *Handbook of Cliometrics*, edited by C. Diebolt and M. Haupert, 1299–1322. Verlag: Springer International Publishing.
Evangelista, M. 1988. *Innovation and the Arms Race: How the United States and the Soviet Union Develop New Military Technologies*. Ithaca: Cornell University Press.
Farrell, T. G., and T. Terriff. 2002. *The Sources of Military Change: Culture, Politics, Technology*. Boulder, CO: Lynne Rienner.
Ferguson, N. 2001. *The Cash Nexus: Money and Power in the Modern World, 1700-2000*. New York: Basic Books.

Fonfría, A. 2014. "Reflexiones sobre la defensa y su financiación: un debate abierto." *Revista de Estudios Europeos* 65 (Jul./Dec.): 67–78.

Fonfría, A., and P. Correa-burrows. 2010. "Effects of Military Spending on the Profitability of Spanish Defence Contractors." *Defence and Peace Economics* 21 (2): 177–192. doi:10.1080/10242690903569007.

Fu, X., C. Pietrobelli, and L. Soete. 2011. "The Role of Foreign Technology and Indigenous Innovation in the Emerging Economies: Technological Change and Catching-Up." *World Development* 39 (7): 1204–1212. doi:10.1016/j.worlddev.2010.05.009.

García Alonso, J. M. 1994. "Introducción a la industria de la Defensa en España." *Cuadernos de estrategia* 64: 67–75.

Gholz, E., and H. M. Sapolsky. 2021. "The Defense Innovation Machine: Why the U.S. Will Remain on the Cutting Edge." *Journal of Strategic Studies* 44 (6): 854–872. doi:10.1080/01402390.2021.1917392.

Gómez, V., and A. Maravall. 1994. "Estimation, Prediction and Interpolation for Nonstationary Series with the Kalman Filter." *Journal of the American Statistical Association* 89 (426): 611–624. doi:10.1080/01621459.1994.10476786.

Gómez, V., and A. Maravall. 1996. "Programs TRAMO and SEATS. Instructions for the User" (Beta versión: September 1996). *Banco de España, Servicio de Estudios*. Working Paper 9628.

Gómez Mendoza, A. 1988. "Government and the Development of Modern Shipbuilding in Spain, 1850-1935." *The Journal of Transport History* 9 (1): 19–36. doi:10.1177/002252668800900102.

Gómez Mendoza, A., and S. López García. 1992. "Los comienzos de la industria Aeronáutica en España y la Ley de Wolff (1916-1929)." *Revista de historia industrial* 1: 155–178.

Goñi Mendizabal, I. 2007. "Evolución de la industria armera vasca (1876-1969): Un enfoque a largo plazo." In *Del metal al motor. Innovación y atraso en la historia de la industria metal-mecánica española*, edited by P. Pascual and P. Fernández Pérez, 385–432. Bilbao: Fundación BBVA.

Goñi Mendizabal, I. 2008. "Imitación, innovación y apoyo institucional. Estrategias de penetración en los mercados internacionales de las empresas armeras vascas durante el siglo XX." *Revista de la historia de la economía y de la empresa* 2: 207–233.

Griffin, S. 2017. "Military Innovation Studies: Multidisciplinary or Lacking Discipline?." *Journal of Strategic Studies* 40 (1–2): 196–224. doi:10.1080/01402390.2016.1196358.

Griliches, Z. 1990. "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature* 28 (4): 1661–1707.

Grissom, A. 2006. "The Future of Military Innovation Studies." *Journal of Strategic Studies* 29 (5): 905–934. doi:10.1080/01402390600901067.

Hall, P., and A. James. 2009. "Industry Structure and Innovation in the U.K. Defense Sector." *The Economics of Peace and Security Journal* 4 (1): 23–29. doi:10.15355/epsj.4.1.23.

Hartley, K. 1998. "Defence Procurement in the UK." *Defence and Peace Economics* 9 (1–2): 39–61. doi:10.1080/10430719808404893.

Hoffman, P. T. 2012. "Why Was It Europeans Who Conquered the World." *The Journal of Economic History* 72 (3): 601–633. doi:10.1017/S0022050712000319.

Hooks, G. 2008. "Military–Industrial Complex, Organization and History." In *Encyclopedia of Violence, Peace, & Conflict* 2ndед. edited by, K. Lester, 1278–1286. Amsterdam: Academic Press.

Instituto de Estudios Fiscales. 1976. *Cuentas del Estado Español, 1890-91 a 1907*. Madrid: Instituto de Estudios Fiscales.

Instituto de Estudios Fiscales. 1979. *Cuentas del Estado Español, 1908 a 1923-24*. Madrid: Instituto de Estudios Fiscales.

Instituto de Estudios Fiscales. 1982. *Cuentas del Estado Español, 1924 a 1935*. Madrid: Instituto de Estudios Fiscales.

James, A. D. 2009. "Reevaluating the Role of Military Research in Innovation Systems: Introduction to the Symposium." *The Journal of Technology Transfer* 34 (5): 449–454. doi:10.1007/s10961-008-9103-1.

Kennedy, P. M. 1987. *The Rise and Fall of the Great Powers: Economic Change and Military Conflict from 1500 to 2000*. New York: Random House.

Khan, B. Z. 2018. "Human Capital, Knowledge and Economic Development: Evidence from the British Industrial Revolution, 1750–1930." *Cliometrica* 12 (2): 1–29. doi:10.1007/s11698-017-0163-z.

Kober, A. 2015. *Practical Soldiers: Israel's Military Thought and Its Formative Factors*. Vol. 107. History of Warfare. Leiden: Brill.

Kollias, C., G. Manolas, and S. M. Paleologou. 2004. "Defence Expenditure and Economic Growth in the European Union. A Causality Analysis." *Journal of Policy Modeling* 26 (5): 553–569. doi:10.1016/j.jpolmod.2004.03.013.

Lamoreaux, N. R., and K. L. Sokoloff. 2005. "The Decline of the Independent Inventor: A Schumpterian Story?" *NBER* Working Paper 11654.

López, S. M., and Á. González Gascón. 2019. "La Hispano Suiza y la aeronáutica: innovar en el primer tercio del siglo XX." In *Pioneros. Empresas y empresarios en el primer tercio del siglo XX en España*, edited by R. Molina Recio, 205–231. Granada: Comares Historia.

López-Rodríguez, G. 2019. "Innovación militar en el Ejército español durante la guerra de Marruecos (1921-1927)." *Revista Española de Ciencia Política* 51: 155–173. doi:10.21308/recp.51.06.

Lozano Courtier, A. 1997. "Estado, importación de tecnología y nacionalización de la construcción naval militar española: la SECN 1909-1935." In *¿Que inventen ellos? Tecnología, empresa y cambio económico en la España contemporánea*, edited by S. López García and J. M. Valdaliso, 281–303. Madrid: Alianza.

MacKenzie, D., and M. Evangelista. 1989. "Technology and the Arms Race." *International Security* 14 (1): 161–175. doi:10.2307/2538768.

MacLeod, C., J. Tann, J. Andrew, and J. Stein. 2003. "Evaluating Inventive Activity: The Cost of Nineteenth Century UK Patents and the Fallibility of Renewal Data." *The Economic History Review* 56 (3): 537–562. doi:10.1111/j.1468-0289.2003.00261.x.

Maddala, G. S., and I.-M. Kim. 1998. *Unit Roots, Cointegration and Structural Change*. Cambridge: Cambridge University Press.

Magee, G. B. 1999. "Technological Development and Foreign Patenting: Evidence from 19th-Century Australia." *Explorations in Economic History* 36 (4): 344–359. doi:10.1006/exeh.1999.0721.

Marín, F., and J. M. Mata. 2010. *Vehículos Blindados en España*. Madrid: Susaeta Ediciones.

Martos Gómez, J. J., and J. M. Ortiz-Villajos. 2022. "¿Hubo modernización de las fuerzas armadas españolas entre 1891 y 1935? Un análisis desde el punto de vista del gasto." *Revista de Historia Industrial-Industrial History Review* 31 (84): 99–143. doi:10.1344/rhiihr.v31i84.31101.

Memorial de Artillería. 1844-1936. Madrid: Imprenta de Eduardo Arias.

Molas-Gallart, J. 1992. *Military Production and Innovation in Spain*. Chur: Harwood Academic Publishers.

Molas-Gallart, J. 1997. "Country Survey IX: Spain." *Defence and Peace Economics* 8 (3): 267–306. doi:10.1080/10430719708404882.

Molas-Gallart, J. 1998. "Defence Procurement as an Industrial Policy Tool: The Spanish Experience." *Defence and Peace Economics* 9 (1–2): 63–81. doi:10.1080/10430719808404894.

Moretti, E., C. Steinwender, and J. Van Reenen. 2021. "The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers". *NBER* Working Paper 26483.

Mowery, D. C. 2010. "Military R&D and Innovation." In *Handbook of the Economics of Innovation*, edited by B. H. Hall and N. Rosenberg, 1219–1256. Vol. 2. Amsterdam: Elsevier.

Nicholas, T. 2010. "The Role of Independent Invention in US Technological Development, 1880-1930." *The Journal of Economic History* 70 (1): 57-82. doi:10.1017/S0022050710000057.

Nicholas, T. 2011a. "Cheaper Patents." *Research Policy* 40 (2): 325-339. doi:10.1016/j.respol.2010.10.012.

Nicholas, T. 2011b. "Independent Invention During the Rise of the Corporate Economy in Britain and Japan." *The Economic History Review* 64 (3): 995-1023. doi:10.1111/j.1468-0289.2010.00586.x.

Nuvolari, A., and V. Tartari. 2011. "Bennet Woodcroft and the Value of English Patents, 1617–1841." *Explorations in Economic History* 48 (1): 97–115. doi:10.1016/j.eeh.2010.09.005.

Nuvolari, A., V. Tartari, and M. Tranchero. 2021. "Patterns of Innovation During the Industrial Revolution: A Reappraisal Using a Composite Indicator of Patent Quality." *Explorations in Economic History* 82: 82. doi:10.1016/j.eeh.2021.101419.

Nuvolari, A., and M. Vasta. 2015. "Independent Invention in Italy During the Liberal Age, 1861-1913." *The Economic History Review* 68 (3): 858–886. doi:10.1111/ehr.12087.

O'Brien, P. K., and P. A. Hunt. 1993. "The Rise of a Fiscal State in England, 1485–1815." *Historical Research* 66 (160): 129–176. doi:10.1111/j.1468-2281.1993.tb01806.x.

Ortiz-Villajos, J. M. 1999. *Tecnología y desarrollo económico en la historia contemporánea. Estudio de las patentes registradas en España entre 1882 y 1935*. Madrid: Oficina Española de Patentes y Marcas.

Ortiz-Villajos, J. M. 2002. "International Patenting in Spain Before the Civil War." *History of Technology* 24: 203–232.

Ortiz-Villajos, J. M. 2014. "Patents, What For? The Case of Crossley Brothers and the Introduction of the Gas Engine into Spain, C. 1870-1914." *Business History* 56 (4): 650–676. doi:10.1080/00076791.2013.837890.

Parker, G. 1988. *The Military Revolution: Military Innovation and the Rise of the West, 1500-1800*. Cambridge: Cambridge University Press.

Posen, B. R. 1984. *The Sources of Military Doctrine: France, Britain and Germany Between the World Wars*. Ithaca: Cornell University Press.

Ram, R. 1995. "Defense Expenditure and Economic Growth." In *Handbook of Defense Economics*, edited by K. Hartley and T. Sandler, 251–274. Vol. 1. Amsterdam and New York: Elsevier.

Rodríguez González, A. R. 2013. "Las Campañas Navales en el Ultramar Español (1875-1898)." *Revista Universitaria de Historia Militar* 2 (3): 9–33.

Rosen, S. P. 1988. "New Ways of War: Understanding Military Innovation." *International Security* 13 (1): 134–168. doi:10.2307/2538898.

Rosen, S. P. 1991. *Winning the Next War. Innovation and the Modern Military*. Ithaca: Cornell University Press.

Ruttan, V. W. 2006. *Is War Necessary for Economic Growth? Military Procurement and Technology Development*. Oxford and New York: Oxford University Press.

Saal, D. S. 2001. "The Impact of Procurement-driven Technological Change on U.S. Manufacturing Productivity Growth." *Defence and Peace Economics* 12 (6): 537–568. doi:10.1080/10430710108405002.

Sabaté Domingo, O. 2015. *Military spending, institutional stability and fiscal capacity. Spain in comparative perspective (1850-2009)*. Doctoral thesis, University of Barcelona.

Sabaté Domingo, O. 2016. "New Quantitative Estimates of Long-Term Military Spending in Spain (1850–2009)." In *Research in Economic History*, edited by C. Hanes and S. Wolcott, 225–276. Vol. 32. Bingley: Emerald.

Sáiz, P. 2005. “Investigación y desarrollo: patentes.” In *Estadísticas históricas de España. Siglos XIX-XX*, edited by A. Carreras and X. Tafunell, 835–872. Vol. 2. Bilbao: Fundación BBVA.

Sáiz, P. 2012. “Social Networks of Innovation in the European Periphery: Exploring Independent versus Corporate Patents in Spain Circa 1820-1939.” *Historical Social Research* 37 (4): 348-369. doi:10.2139/ssrn.3495929.

Sáiz, P. 2014. “Did Patents of Introduction Encourage Technology Transfer? Long-Term Evidence from the Spanish Innovation System.” *Cliometrica* 8 (1): 49–78. doi:10.1007/s11698-013-0094-2.

Sáiz, P., F. Llorens, L. Blázquez, F. Cayón, and dirs. 2000-2008. *Base de datos de solicitudes de patentes (España, 1878-1939)*. Madrid: OEPM-UAM. http://historico.oepm.es.

Sáiz, P., and D. Pretel. 2014. “Why Did Multinationals Patent in Spain? Several Historical Inquiries.” In *Organizing Global Technology Flow: Institutions, Actors, and Processes*, edited by P. Y. Donzé and S. Nishimura, 39–59. New York: Routledge.

Sánchez Sánchez, E. M. 2006. “Armamento e instrucción militar. Francia y la modernización del ejército español, 1948-1975.” *Ayer* 63 (3): 211–232.

San Román, E. 1999. *Ejército e Industria. El nacimiento del INI*. Barcelona: Crítica.

Schankerman, M., and A. Pakes. 1986. “Estimates of the Value of Patent Rights in European Countries During the Post-1950 Period.” *The Economic Journal* 96 (384): 1052–1076. doi:10.2307/2233173.

Schmid, J. 2018a. *The Determinants of Military Technology Innovation and Diffusion*. Georgia Institute of Technology, Atlanta. http://hdl.handle.net/1853/59877.

Schmid, J. 2018b. “The Diffusion of Military Technology.” *Defence and Peace Economics* 29 (6): 595–613.

Schmid, J. 2022. “Technological Emergence and Military Technology Innovation.” *Defence and Peace Economics* 1–19. doi:10.1080/10242694.2022.2076339.

Singer, J. D. 1987. “Reconstructing the Correlates of War Dataset on Material Capabilities of States, 1816–1985.” *International Interactions* 14 (2): 115–132. doi:10.1080/03050628808434695.

Stone, L., edited by. 1994. *An Imperial State at War: Britain from 1689 to 1815*. London: Routledge.

Streb, J., J. Baten, and Y. Shuxi. 2006. “Technological and Geographical Knowledge Spillover in the German Empire 1877–1918.” *The Economic History Review* 59 (2): 347–373. doi:10.1111/j.1468-0289.2006.00347.x.

Sullivan Faith, K. 2013. *Patterns of Creation and Discovery. An Analysis of Defense Laboratory Patenting and Innovation. Pardee RAND Graduate School Dissertation Series*. Santa Monica: RAND Corporation.

Toda, H. Y., and T. Yamamoto. 1995. “Statistical Inference in Vector Autoregressions with Possibly Integrated Processes.” *Journal of Econometrics* 66 (1–2): 225–250. doi:10.1016/0304-4076(94)01616-8.

Tortella, G. 2000. *The Development of Modern Spain*. Cambridge: Harvard University Press.

Van Creveld, M. 1991. *Technology and War. From 2000 B.C. to the Present*. New York: The Free Press.

Vasta, M. 1999. *Innovazione tecnologica e capitale umano in Italia (1880-1914)*. Bolonia: Il Mulino.

Vicente Oliva, S. 2019. “Protección del conocimiento y de tecnología con utilidad en defensa.” *Economía Industrial* 412: 77–88.

VV.AA. 2000. “Economía de la defensa.” *Economistas* 85 (XVIII).

Weber, R. 2001. *Swords into Dow Shares: Governing the Decline of the Military-Industrial Complex*. Boulder: Westview Press.