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ABSTRACT

Military Spending and Innovation: Learning from 19th Century World Fair Exhibition Data*

We provide quantitative evidence on the relationship between military spending and innovation in the 19th century. Combining innovation data from world fairs and historical military data across Europe, we show that national military spending is associated with national innovation towards war logistics such as food processing, but less towards war technology such as guns. This pattern reflects differences in the historical markets for war supplies. European patent data of 1990-2015 suggest a long-term correlation between historical and con- temporaneous innovation patterns.

JEL Classification: H56, O31, O14, N43

Keywords: military spending, innovation, war logistics, food processing, military supply, 19th century

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An army marches on its stomach.

Napoleon Bonaparte

If the Prussian needle-gun contributed in a great measure to the defeat of the Austrians at Sadowa, it is none the less true that the famous Erbswurst, or peasausage, of the Germans had much to do with their maintaining the siege of Paris during the long cold winter months of that capital's investment.

Pritchard (1877)

1 Introduction

What is the role of the military for national technological progress across economic sectors, i.e. the direction of innovation? Recent research shows a positive relationship between military-related R&D and innovation after WWII (Gross & Sampat, 2020; Moretti et al., 2019). Yet, no quantitative evidence exists regarding the role of the military in the 19^{th} century, a period when warfare became a tool for nation building (Tilly, 1990)[1] and when the rate of innovation reached its historical peak (Gold, 2021; Huebner, 2005; Naudé & Nagler, 2021). While governments at the time had low spending-to-GDP ratios, they devoted most of their national budgets to the military sector (Ferguson, 2001; Voigtländer & Voth, 2013). Mass armies were mobilized and the scope of wars increased in terms of speed and distance. The introduction of conscription made the provision for standing (i.e., permanent and professional) armies a permanent cost factor, inducing fiscal pressure for innovation (Thompson & Rasler, 1999). Rapid technological change affected all sorts of equipment. The precision and shooting distance of rifles and guns improved significantly. Steam-powered warships replaced sailing ships. Improved war logistics helped to increase the speed and scope of operations (Onorato et al., 2014) and to overcome the century-old challenge that the majority of troops were lost to diseases and hunger (Shay, 2011; Voigtländer & Voth, 2013). Yet, the states did not directly engage in innovative activities, reflected in negligible *public* military-related R&D expenditures. Instead, 19^{th} century governments influenced innovation through military demand for products and processes developed by *private* innovators who were often engineering entrepreneurs (Hacker, 2005; Ruttan, 2006). The military further stimulated private innovation through national inducement prize contests or generous purchases of technologies. Among the required warfare inputs, two were decisive for military success: products in war technology (i.e., weaponry or warships) and war logistics (i.e., preserved foods for the supply of armies) (Barrett & Cardello, 2012).[2] The markets for these two groups of warfare supplies had, however, different geographic scope: While guns and canons were predominantly sourced from few dominant global producers (e.g., the Birmingham or Lüttich gun trade) supplies for war logistics and (perishable) food stemmed from national or subnational sources (Ongaro, 2020). Ample anecdotal evidence suggests that food innovation was pivotal for the military to solve the problem of food perishability: for instance, Napoleon III offered a prize for finding a preservable and transportable low-cost substitute for butter, leading to the invention of margarine in 1869 (Gander, 1970). Apart from evidence in historiography or business history, no quantitative investigation has so far illuminated the historical role of the military for national innovation systems across countries.

This paper provides the first quantitative assessment of the relationship between military spending, measured as military expenditures divided by GDP, and the innovative structure (i.e., the direction of technological change across economic sectors) in Europe in the 19^{th} century. The differential nature of markets in *war technology* vs. *war logistics* suggests that the innovation response to national military expenditures may differ across war inputs. Based on the geographic reach of historical supply and demand chains, we investigate differences in the role of the military sector for weaponry vs. food supplies. We expect a comparatively stronger link between military spending and national food innovation. Finally, by analyzing contemporary EPO patent data, we provide a tentative assessment of the long-term persistence of historical innovative structures across countries.

To measure the direction of national innovation activities, we utilize exhibition data from two famous world expositions, the *Great Exhibition* of London in 1851 and the *Centennial Exhibition* of Philadelphia in 1876. The data contain more than fourteen thousand harmonized observations of innovative exhibits from inventors residing in 16 European countries. The innovations at both fairs reflect final products from a broad range of technologies, which we—following the classes of the exhibition catalogues—group into food processing (to proxy for *war logistics*), machinery (to proxy for *war technology*, including the navy)[3] and other technologies (including mining, chemicals, scientific and medical instruments[4], household articles or textiles). We assign the innovation data to countries based on the origin of innovators and combine them with national military expenditures, military personnel, the occurrence of wars, and population data from the Correlates of War project. Finally, we add a rich set of country characteristics related to economic development, access to the sea and geography. The focus of the analysis is on central and northern European countries to diminish the potential impact of unobserved characteristics that might result from the inclusion of culturally more dissimilar countries. The states in our sample exhibit significant variation in military and innovation patterns. Using multinomial logit regressions at the exhibit level, we assess the prevalence of innovative activities in *war logistics* vs. *war technology* (as compared to other technology classes) for countries featuring different levels of national military spending. Using cross-country OLS regressions, we also estimate the relationship between military spending and the total level of innovation across countries.

We find strong and significant associations between 19^{th} century national military spending and innovative activities in food processing, and to a lesser and less robust extent in war technology. Moreover, countries with higher military expenditures shifted innovative activities towards food processing, as implied by the fact that military spending and the total level of innovative activity per country are unrelated. The shift in the innovative structure of countries across economic sectors reflects the incentives to innovate nationally in the food sector. In terms of economic significance, an increase in the military spending by one percentage point corresponds to a 2.2 percentage point increase in the likelihood for a domestic inventor to innovate in food processing. Since the average share of food processing innovation across all countries corresponds to around 7.0 percent and the average military spending corresponds to 2.0 percent, the strength of this association is economically meaningful. We show that this positive relationship is driven by the capital intensiveness per serviceman rather than the size of the army. Our results are robust to different sets of control variables, the omission of single countries and different empirical specifications, including those with country fixed effects. The findings are also robust to permutation tests.

Using European Patent Office (EPO) patent data from 1990-2015 we also show suggestive evidence that the military sector of the 19^{th} century was not only related to innovation patterns in the short-run, but possibly also in the long-run. Our findings suggest that the historical demand for logistical military equipment (e.g., food) has been conducive to the shape of the innovative structure across Europe.

We contribute to several strands of literature: First, our paper relates to a large research body on warfare and innovation, which mostly focuses on the post-WWII period and on the US (Mowery, 2010, for an extensive survey see). There is a general lack of cross-country work on the link between the military sector and innovation (Mowery, 2010).[5] Therefore, we complement prior studies using innovation data from historical world exhibitions (e.g., Moser, 2005, 2011, 2012) by introducing the military sector into this context. While economists and historians agree that the military has been important for recent technological advances, the military revolutions of the 19^{th} century have remained a blind spot. Our paper also relates to research on the relationship between public sector spending and innovation (e.g., Azoulay et al., 2019; Jacob & Lefgren, 2011). While most previous studies focus on public R&D expenditures, a distinguishing feature of our 19^{th} century setting is that we study the relationship between the military sector and innovation without public military R&D. Instead, innovation followed public product demand and originated mostly from trial-and-error processes of privately funded, profit seeking inventor-entrepreneurs (Hughes, 2004). Furthermore, our setting and data allow us to explore the relationship between innovation and other military-related variables such as army size and the occurrence of wars. More generally, our paper adds to the small but growing literature on determinants of the direction of technological change such as factor endowments (Hanlon, 2015) or labor supply (Danzer et al., 2020).

Second, our paper highlights the role of innovation at the crossroads of civic and military innovation and contributes to the security literature, which is divided over the role of civilian vs. military innovations (Rosen, 1988). Our results suggest that military expenditures correspond stronger with war logistics than with weaponry, mirroring the incentives from heterogeneous war supply structures. Accordingly, the military had an active role for private, civic innovation long before the emergence of the military-industrial complex in the 20^{th} century (Hughes, 2004). Given that innovation in war logistics (e.g., in food preservation) had significant added value in civic applications in the long run, our research also contributes to the literature on dual-use applications of military innovation (Acosta et al., 2011; Cowan & Foray, 1995). In retrospect, many 19^{th} century inventions in war logistics turned out to be important dual use technologies with civilian applications in food preservation and transportation (e.g., the invention of food canning, dried foods or margarine). Hence, exploiting historical data can shed light on the roots of innovation processes and incentives that may no longer be self-evident.

While the correlation between military spending and food innovation is evident in our data, we cannot address the question of causality: Since demand (military spending) and supply (innovation) interact on the market for military supplies, any identification of causal effects would need to rely on truly exogenous variation in either military spending or in innovation. Unfortunately, the historical context does not provide any source of exogenous variation for our setting and data. However, given the accounts on the historical market structures, our findings are plausibly in line with an interpretation that *national* military demand incentivized *national* innovation in areas characterized by *national* production.

The remainder of this paper is as follows: Section 2 describes the institutional background. Section 3 presents the data sets, descriptive statistics and empirical approach of the paper. We present the results and robustness analyses in Section 4. Section 5 discusses a tentative long-term relationship between military expenditures and innovation, while Section 6 concludes.

2 Institutional Background

2.1 The Historical Context

Historians depict the 19^{th} century as the era of nation building and the transition to modernity (Ferguson, 2001; Hobsbawm, 2006). Innovation fueled the industrial revolution and magnified the scale and scope of human interaction and connectedness, leading to what has been called the first wave of globalization. With the emergence of the nation-state, a set of innovation related institutions was formalized, such as patent laws.

An important instrument for the creation of national cohesion was modern warfare. War was no longer a struggle for supremacy between ruling dynasties, but a fight between nations. Mercenary armies were replaced by standing armies and conscription of citizens (Rowe, 2017). Owing to the fundamental changes in technology and polity, the size and scope of warfare increased substantially. According to historians, two factors became decisive for the military success of armies: their *war technology*, for instance with respect to gun and rifle shooting power or precision, and their *war logistics*, for instance with respect to food supply, transportation or communication (Landers, 2005; Wilson, 2001). Some historians rate the importance of war logistics even higher than that of war technology, but armies excelling in both were most successful in the 19^{th} century (Barrett & Cardello, 2012; Boot, 2006; Creveld, 2004; W. Murray & Millett, 1996).

The most pivotal area of war logistics was the supply of food: First, food was (and still is) essential since the success of warfare directly depends on the food intake of soldiers (Hill Neil et al., 2011). Medicine and hygiene in the army was strongly interlinked with food provision as malnourishment and contaminated / adulterated food was a major health threat during campaigns (e.g., scurvy) (Collins, 1993). For centuries, more soldiers had died from hunger, scurvy or infectious diseases than from the weaponry of the enemy, highlighting the problem of food supply in both, the army and navy. For instance, only 10 percent of dead French soldiers in the Crimean War (1854-56) were killed on the battleground (Derstine, 1991). Second, food has been intensively deployed as war weapon for centuries. Scorched earth policies have been used throughout history, including in the American civil war (1861-65) and the Boer wars (1880-81, 1899-1902). Famishment of sieged cities was, and still is, one of the cruelest military strategies. Third, the dramatic geographic expansion of war zones in the 19^{th} century exacerbated the challenge of supplying mass armies with nonperishables. While food preservation had always been a challenge, the 19^{th} century delivered significant break-through innovations (e.g., in canning or dehydration).

Instead of investing in public R&D, governments effectively incentivized private innovation in the areas of war technology and war logistics by stimulating demand for modern military equipment. Before the 19^{th} century, the focus was mostly on armament and war technology: During the 16^{th} to 18^{th} centuries, the British government tried to influence military innovation through initiatives to establish cannon fabrication or the demand for iron and weapons (Lundvall & Borras, 2004). In the 19^{th} century, military inventions resulted in increasingly complex weapons (Mowery, 2010). Of similar importance, but less salient in the literature, were food processing techniques. Standing armies increased the necessity for food security and preserved foods. A number of historical military writings confirm that food preservation was of utmost importance to army staff (Beckerhinn, 1875; Erlach, 1865). For warfare, the military had to rely on non-perishable rations with low space requirements that could be added to the field packs of soldiers. This was achieved through techniques such as compression or dehydration. Innovations in food processing enhanced the mobility, geographic scope, logistics and security of the food supply of the new mass armies with little disruption of military strategy (Prahl & Setzwein, 1999). Preserved food was almost exclusively purchased by the military as it was expensive *and* often unappealing to the taste of the people (Bresnahan & Gordon, 2008; Carolan, 2011). In fact, food inventions were explicitly tailored to the requirements of the military complex in its quest for making warfare more efficient (Drouard & Oddy, 2016). Yet, while the top-down command structure of the military secured reliable demand for preserved foods, the resistance of the military leadership to internally innovate led to a system in which private rather than public innovators invented products suitable for governmental consumption (W. Murray & Millett, 1996).

2.2 Innovation and the Market for War Supplies

At the beginning of the 19^{th} century, governments spent around two thirds of their budgets on the military; they relied on private entrepreneurs for the delivery of warfare supplies (Torres-Sánchez et al., 2018). Military procurement in the 19^{th} century was characterized by the interplay (rather than crowding-out) of governments and private inventors (Harding & Solbes Ferri, 2012). Government departments entered the marketplace for warfare equipment and logistics as 'contractor states': instead of producing warfare supplies directly, they sourced them from private businessmen and thereby secured their loyalty (Enciso, 2018; Mowery, 2010). Private entrepreneurs used contracts with the military as a means of complementing and smoothing the civilian demand they faced. The army leaderships' explicit specifications of warfare demand and the corresponding military contracts acted as drivers of innovation (Torres-Sánchez et al., 2018).

Innovation in the 19^{th} century was the result of private inventors' quest to generate profit from marketable innovation; these inventor-entrepreneurs were often flexible with respect to innovating in specific product groups (Boot, 2006; Hughes, 2004). Therefore, public institutions provided the guidance: In many instances, governments incentivized innovation in the private sector through inducement prize contests or life annuities for inventors. The innovation effect of such incentives was significant and immediate in the 19^{th} century (Brunt et al., 2012; Moser & Nicholas, 2013).

Inducement prices were quite common across Europe (F. Murray et al., 2012); tenders were invited by international competitions, government bodies, royal decrees, national research institutes or associations, and private companies (Brunt et al., 2012; Khan, 2015; Kotar & Gessler, 2014; Moser & Nicholas, 2013). As early as 1795, Napoleon announced a prize contest which ultimately led to the development of canning for army food and initiated a host of inventions for reliable food preservation. In the 19^{th} century, the search for methods of food processing accelerated. The military significance of several such inventions is well documented in the historical literature: shortly before the Franco-Prussian war, Napoleon III offered a prize for inventing a low-cost substitute for butter, leading to the creation of margarine in 1869 (Gander, 1970). Private entrepreneurs started inventing preserved foods and synthetized food additives for the military (Prahl & Setzwein, 1999). The novel patent of one of the first privately developed instant food products, the 'Erbswurst' (German split pea soup), was purchased by the Prussian government. The army performed tests on its military suitability and fed it successfully during the Franco-Prussian war (Peter, 2008). Many of today's most well-known brands for preserved or instant foods were established during the 19^{th} century (e.g., Batchelors, Bovril, Campbell, Knorr, Liebig, or Maggi).

This *military supply structure* of the 19^{th} century was not dominated by large industrial producers. In fact, supply relations where characterized by small producers which experimented and responded to technological challenges (Behagg, 1998). Large suppliers entered the market only during high-demand periods, i.e. during wartime (Ongaro, 2020). Private businessmen responded to military machinery demand (e.g., guns, rifles) as well as to the demand for 'civilian' military equipment (war logistics), such as uniforms, boots or food (Church, 1970; Ongaro, 2020).

The *military demand structure* differed between war machinery and war logistics. While guns and rifles were often purchased on international markets (e.g., the famous gun trades of Birmingham and Lüttich), food supplies were more often purchased from national or even regional producers, not least owing to the perishability of food (Behagg, 1998; Ongaro, 2020). The international sourcing of arms emerged since production and trade of weapons were dominated by few internationally recognized production centers operating at the technological frontier with strong economies of scale (Krause, 1992). These arms trades became relatively free in the mid-19th century. At the same time, lower tariffs and cheaper costs of transportation stirred competition for European agricultural producers from US farmers (Bairoch, 1972). Supply and demand structures considered, the incentives to spur national innovation was relatively stronger in *war logistic* supplies than in *war machinery* in the 19th century.

The market structure for weaponry vs. food supplies differed significantly in the 19th century, as summarized in Table 1 (see Grant (2007), Lehmann-Russbüldt (1929), Spiekermann (2018), Teuteberg (2007), Voit (1876), and Wehberg (1919)): While weapons were sourced through national coordination offices, the demand for food remained regional, e.g., in the responsibility of victualling offices in each harbor or garrison. The demand for weapons took the form of large but irregular orders, while food was continuously sourced. On the supply side, weapons were produced by a limited number of global suppliers, while competition between regional and national suppliers of food was fierce. In summary, weapons were traded in an equally powerful customer-seller relationship, in which several arms producers were suspected of colluding. In the food market, regional monopsony power made small producers compete for profitable military contracts; good relations to the army or navy have reportedly helped in winning bids (Spiekermann, 2018). Weaponry firms, like Krupp, strategically served the global market in order to smooth the demand for weapons; to this end, World Exhibitions were important networking arenas (Mogensen, 1999; Wolbring, 2002). Food companies, like Von Effner (egg powder), combined the production for military and civilian customers to be less dependent on profitable military contracts (Voit, 1876). Military food supplies were national across Europe in the 19^{th} century (Collins, 1993).

3 Data and Empirical Approach

To assess the historical link between national military expenditures and the direction of technical change empirically, we combine exhibit-level innovation data from inventors residing in 16 different European countries with historical country-level data on the military sector, economic development and geography (see data description and variable definitions in the Online Appendix).[6]

3.1 World Exhibition Data

To measure innovation we rely on unique historical data on exhibits at two 19^{th} century World Exhibitions, first introduced by Moser (2005). Countries presented their latest inventions at *The Great Exhibition of the Works of Industry of All Nations* in London in 1851 and at the *Centennial International Exhibition* in Philadelphia in 1876. Even for today's standards, the dimensions of both world exhibitions were huge: the edition of 1851, the first of its kind, attracted more than six million visitors and in 1876 the number of visitors was already around ten million.

To improve consistency across time we complement the exhibit-level data by Moser (2005) with hand-collected (and previously unused) data from the official exhibition catalogue of 1851 for three German states: 'Baden', 'Mecklenburg Schwerin' and 'Hanover'.[7] The final sample contains more than fourteen thousand exhibits from inventors located in 16 central and northern European countries. Following Moser (2005) we exclude southern Europe to diminish the impact of unobserved country characteristics, such as culture. This data set is unique in allowing the investigation of innovation in the 19^{th} century. Unlike patents, the exhibits are final products ready for marketing. Additional key advantages of the data are the high level of harmonization and the inclusion of countries without patent laws (such as

Switzerland and, intermittently, the Netherlands).

However, a potential concern is that the exhibition data are prone to other types of selection. First, potential selection might occur with respect to which innovations are showcased at the exhibitions: Exhibitions might be subject to space restrictions, exhibits might be selected owing to transportation costs, and producers might be reluctant to display easily imitable exhibits. Yet, in fact, exhibition space was regularly added on request and heavy or complex exhibits were displayed as demagnified models (Moser, 2005). The selection of items was proposed by national commissions which applied internationally comparable and well-documented criteria (mainly novelty and usefulness) (Zollvereins-Regierungen, 1853). Those jury reports were published, making the selection process highly transparent (Moser & Nicholas, 2013). The risk of intellectual property theft was reduced by displaying final products (e.g., food items) rather than the novel underlying production processes. The exhibition organizers offered a cheap and fast-track on-site patent system, which was, however, used by only few exhibitors. Moser (2005) interprets this as low demand for protection. Second, selection might be prevalent in specific product groups relevant for military purposes. Potential secrecy concerns in weaponry are contradicted by the fact that both Exhibition featured a significant number of 534 weapon exhibits (4 percent of the total). This is unsurprising, given that the market for weaponry required producers to network intensively with diverse customers at

International Fairs. A well-documented case is the Prussian Krupp Gusstahlfabrik after the 1851 exhibition, which sold steel guns and breachload guns to antagonistic parties like the British Royal Navy, Prussian Navy, Austro-Hungarian Navy, Spanish Navy, Russian Empire, Kingdom of Greece, and the Ottoman Empire. At the political level, the exhibition of military weaponry innovation was seen as a matter of national pride and might have potentially acted as strategic deterrence (**montgomery99**; Grant, 2007; Heimsoth, 2014; Mogensen, 1999; Swift, 2007).

Based on the product class structure of the exhibition catalogue we group exhibits into one of three mutually exclusive technology classes, using the description of the exhibits: 'food processing' (relevant for *war logistics*), 'machinery' (the product class containing weaponry (*war technology*) but also vehicles and ship equipment) and 'other technologies'. Food processing is a good proxy for war logistics as food preservation was the main area of non-weaponry war innovation in the 19^{th} century. We demonstrate the dominance of food preservation in food processing exhibits by exploiting the fact that the French exhibition data as of 1851 contain full text descriptions:[8] applying a text-mining algorithm reveals that 'preserv' is the most frequent word stem appearing in 32 percent of all French food processing exhibits (Figure 1). A brief summary of exhibits indicates that food processing and machinery capture the important role of military innovation well. The most relevant food exhibits for military purposes are those relating to preserved or durable foods: for instance, fiftytwo and twenty-seven percent of all food exhibits belong to that group for France and Britain, respectively. However, other food products without direct reference to the military (like alcohol, coffee or chocolate) have also been included in the field rations of soldiers, since they were perceived as stimulants Teuteberg (2007). And finally, some primary food commodities (like farina or starch) were widely used as intermediary inputs for preserved food items. Hence, we think that the broad food category is a good proxy for innovations spurred directly or indirectly by military demand. Any irrelevant food item will add noise to our data and render our food results less precise.[9] Nonetheless, it is important to point out that we are not able to explicitly tailor the exhibition categories according to the military use of exhibits.

3.2 Military Data

We combine the exhibition data with data on historical military expenditures and military personnel from the National Material Capabilities data set (v4.0 and v5.0) produced by the Correlates of War (COW) project (Singer et al., 1972). Building on that, we generate the variables 'military spending' (military expenditures as percentage of GDP), 'military personnel' (measured in logs) and 'expenditures per serviceman' (measures as total military expenditures over military personnel). We create a dummy on the incidence of interstate wars during the 25 years before each exhibition, using the COW War Data (Sarkees & Wayman, 2010).

3.3 Additional Country-Characteristics

We collect historical country-level characteristics to account for factors that might influence the specialization on food or machinery. Data on total population are from the COW Project. We use GDP data from Maddison (1995, 2001). Given the rapid technical progress in the navy and the importance of preserved food for seafaring, we construct a dummy indicative of whether a country is landlocked. This variable can also capture the fact that some countries require less civilian shipping equipment, which is part of the 'machinery' category. Finally, the landlocked dummy accounts for limited market access, which relates negatively with patenting activity in the 19^{th} century (Sokoloff, 1988). Since agricultural potential might influence innovation related to food processing, we further employ data on the percentage of arable land from Ashraf and Galor (2013).[10] We also control for the existence of a patent system using information from Lerner (2000) and Coryton (1855) to account for Moser's (2005) finding that patent laws can influence the direction of innovation towards technology classes such as machinery. Finally, to employ an alternative welfare measure reflecting nutritional intake, we complement our data set with historical average country-level body height from Baten and Blum (2015).

3.4 Summary Statistics

Table 2 presents the summary statistics. Seven percent of all innovations classify as food processing, 17 percent are in machinery and the remaining 76 percent belong to other classes. The average inventor in our data set is exposed to military spending of around 2.0 percent of national GDP. This reflects total military spending of 1.09 billion USD (in 1990 USD) in each country. The average army size is 209 000 servicemen, yet with very large variation across countries. Forty percent of exhibits are associated with a country that was at war within the past 25 years.

3.5 Descriptive Evidence

A comparison of exhibits from 'food processing', 'machinery' and 'other technology classes' reveals that food processing innovation originates from countries that spend relatively more on their military (Figure 2). Furthermore, Figure 3 plots the country-level share of food innovation in all inventions against 19^{th} century military spending. The unconditional relationship is strongly positive suggesting that countries which spend more on their armies also innovate more in food processing. Military spending has substantial explanatory power regarding the overall variation of food innovation as indicated by the goodness-of-fit measure (R-squared = 0.26). The cross-country relationship between military spending and the share of machinery innovation is only about half as strong (Figure 4), while the respective correlation with the share of other technology classes is virtually zero (Figure 5). These scatter plots suggest that military spending in the 19^{th} century was strongly associated with both technology classes relevant for warfare (*war technology* and *war logistics*), but not with the remaining classes.

3.6 Empirical Approach

To analyze the association between military spending and the direction of technological change econometrically, we choose a model that compares the technology classes of exhibits from inventors exposed to different military expenditures in their home countries. The dependent variable is the prevalence of the three mutually exclusive technology classes: 'food processing', 'machinery', and 'other'; each exhibit is assigned to one of these three unordered classes. A simple version of the exhibit-level multinomial logit model is:

$$p_{ijct} = \frac{exp(\ \alpha_j\ +\ \beta_j\ military_{ct}\ +\ X_{ct}\ \gamma'_j)}{\sum_{k=1}^{3}\ exp(\ \alpha_k\ +\ \beta_k\ military_{ct}\ +\ X_{ct}\ \gamma'_k)}, \qquad j=1,2,3. \tag{1}$$

where i indicates a single innovation, j corresponds to the technology class, c is the inventor's home country, and t is exhibition year. The key explanatory variable $military_{ct}$ corresponds to military expenditures divided by GDP of country c in year t. The coefficient of interest β indicates a relative change in innovative activity in technology classes ‘food’ or ‘machinery’ as compared to the ‘other’ technology class. The vector of covariates X includes country-year level variables, such as log population, GDP per capita, the share of arable land and a dummy for landlocked countries. Further, we add a dummy for the existence of a patent system and an exhibition fixed effect for 1876. We cluster standard errors at the country-year level. With only 16 countries in the sample, our number of clusters is low. For the computation of standard errors, we use critical values derived from a T (G-1) distribution; however, the cluster-robust variance might be underestimated in our case, especially since clusters are not well-balanced. While some practitioners suggest that clustering may make matters worse, estimating our multinomial logit models without clusters yields substantially smaller standard errors.

For robustness and for assessing the total level of innovation per country, we also run country-level OLS regressions, in which the number of exhibits per country serves as alternative outcome variable.

4 Results

First, we present our main results at the exhibit level (Section 4.1). This is followed by additional results from the country-level analysis; in this set-up, we also assess the relationship between military spending and the total level of innovation per country (Section 4.2). Then, we test the robustness of our results when accounting for further covariates (Section 4.3). Finally, we investigate the robustness of the results using alternative samples (Section 4.4) and alternative empirical specifications (Section 4.5). Our previously reported findings are remarkably robust across these tests.

4.1 Main Results: Exhibit-Level Analysis

In the multinomial model (Table 3) an increase in military spending is statistically significantly and positively associated with the probability to innovate in food processing (*war logistics*, Panel A) as compared to other technology classes. This finding holds for different sets of country-specific covariates, in the pooled sample (columns 1-3) as well as in cross-sectional model for each World Exhibition in 1851 and 1876 separately (columns 4-5). The results on the relationship between military spending and machinery innovation (*war technology*) are less robust: albeit we find a positive and significant correlation in both cross-sections, the estimate is not significantly different from zero at conventional levels in the pooled sample (Panel B).

There are four notable covariates: the significantly positive exhibition fixed effect suggests a significant increase in food processing innovation between the two world exhibitions. At the same time, there is no apparent time trend for machinery. GDP per capita seems to be negatively associated with food processing (at least towards the end of the 19^{th} century) but positively with machinery. The share of arable land in a country is positively associated with food processing but negatively with machinery. Finally, in line with the importance for the navy landlocked countries innovate less in food processing and less in machinery.

Since coefficients of multinomial logit models need to be interpreted relative to the base category, we compute average marginal effects and marginal effects at the mean of military spending on the propensity to innovate in each technology class. These marginal effects are positive and highly significant for food exhibits (Table 4): an increase in military spending by one percentage point is associated with a 2.2 percentage point higher probability to innovate in food processing on average. By contrast, machinery innovation is not significantly correlated with military spending. It should, however, be noted that machinery is a broad product class that may potentially yield imprecise estimates.

For illustrative purposes and to provide an intuitive explanation of the effect sizes, we calculate predicted shares by technology classes for inventors in countries with low (5^{th} percentile: Sweden in 1876) vs. high (95^{th} percentile: France in 1876) military spending.[11] The predicted probability to innovate in food processing of an inventor located in a country with high military spending is about 5 percentage points (or a full 100 percent) higher compared to an inventor in a country with low military spending (Figure 6). At the same time, shifting from low to high military spending increases the predicted share of technology class 'machinery' by roughly

60 percent.

We interpret our finding in the framework of national military demand for products and processes. Given that the exhibits at the World Fairs included both, final products for marketing (e.g., specific guns or specific preserved food) as well as mechanisms and methods of production (e.g., loading devices for guns or specific lids for conservation tins), governments could immediately conclude contracts for products and processes.

What are plausible channels through which military spending correlates with innovation? Higher overall military spending can reflect an expansion in the size of the army and/or a quality improvement (i.e., capital intensity) per serviceman (e.g., when soldiers are equipped with better guns, food etc.). According to historiography, rising military expenditures per serviceman were the main driver of technological innovation in the 19^{th} century, whereas army sizes expanded roughly in line with population size (Ferguson, 2001, pp. 30–50). Therefore, improvements in war logistics and war technology should be more strongly reflected in military expenditures per serviceman (in 1000 USD as of 1990) as compared to army size (measured by the log of military personnel). Indeed, we find that the impact of the military on food processing is mediated through capital intensity rather than through the headcount, as illustrated in Panel A of Table 5. The marginal effects of this more detailed specification in Table 6 suggest that inventors in countries whose armies operate with greater military capital intensity also innovate more in food processing. Overall, the results indicate that—among the two complementary war technologies—innovation in food processing was more responsive to national military demand in the 19^{th} century. Moreover, innovation in food processing is associated with a quality improvement of armies rather than an expansion of the armed forces.

One concern may be that the broad machinery category leads to measurement error in the dependent variable. While we think there are good reasons to use broad categories, since some military inventions in the machinery category are not necessarily classified as weapons (e.g., aiming devices, carriages, loading equipment, loading mechanisms), we additionally hand-collect all weapon exhibits in the original catalogues: we find 534 weapon exhibits (or one quarter of the entire machinery class). When repeating our multinomial logit estimation with the three new possible outcomes (food, weapons, and the rest), we find no significant correlation between *national* military spending and *national* weaponry innovation, while the significant correlation between food and military spending remains (Table 12 in the Appendix). This seems plausible given that the market for weapons was global while food supply markets were regional or national and, thus, more directly related to national military spending.

4.2 Country-Level Analysis

We also investigate the link between military spending and innovation at the country, rather than exhibit, level (see Table 11 in the Appendix for descriptive statistics). These OLS regressions with only 24 observations do not only serve as a conservative robustness check, but also allow us to investigate whether a country's greater military spending is associated with more innovation overall, as measured by the total number of exhibits per country. While there is a significantly positive relationship between military spending and the total number of exhibits (Table 7, col. 1), this correlations becomes insignificant once we account for our standard set of country-level covariates (col. 2).

Unsurprisingly, population size is particularly strongly related to the number of exhibits per country. Quite differently, the military spending at the country level is strongly correlated with the absolute and relative importance of specific innovation classes: countries with more military spending show more food processing exhibits and have a greater share of food processing innovations in total innovations (Table 7, col. 3-6). The raw correlations of military spending with share and level of machinery innovation are also significantly different from zero (col. 7 and 9); however, these correlations disappear after including control variables (col. 8 and 10). Overall, the country-level analysis suggests that countries with larger military expenditures are not necessarily more innovative overall, but innovate more often in the area of food processing, which was a crucial part of war logistics at that time.

To test the stability of our results, we repeat the analysis, excluding one country after another. It is reassuring that the correlation between military spending and the number as well as share of food inventions remains significant in all cases. The correlation between military spending and machinery inventions is mostly insignificant in the full control specification, as in Table 7 (results available upon request).

Additionally, we perform a series of permutation tests. Permutation is a procedure to reshuffle the data set in a random manner and test the likelihood of the hypothesis test statistic of the observed data against the background of the permuted distribution. This Monte Carlo based method is useful when sample sizes are small, as in our case. We conduct three sets of permutations: First, we permute the dependent variable in 1000 repetitions, i.e. the number of exhibits in food and in machinery across countries and years. Second, we permute the main explanatory variable in 1000 repetitions, i.e. military spending, across countries and years. Finally, we account for the fact that permuting *observed* military spending values is restrictive as the countries in our data set have chosen only 24 out of a large number of *potential* alternative values of military spending. Therefore, we first create a randomly permuted data set of 2000 potential values of military spending (almost 100 per country) and then perform 1000 permutations based on this data set. The results of all permutation tests confirm that military spending is significantly related to food processing, but not to war machinery (Table 13).

Finally, we also test the robustness of mechanisms in the cross-country set-up. We find, like in the exhibit level regressions, that the capital intensity per serviceman is predominantly associated with innovation towards the food category. The size of the army is unrelated to the direction of innovation (Table 14).

4.3 Testing Alternative Explanations

We test whether the observed patterns are driven by three alternative explanations: First, countries that have recently fought a war may consequently have larger armies or greater military spending. Therefore, we include an indicator for whether a country has fought an interstate war in the preceding 25 years in a robustness check. As shown in Panel A1 of Table 8, controlling for past war activity does not change our results for food innovation. However, the positive marginal effect for machinery (war technology) becomes now highly significant. These findings somewhat qualify the literature on more recent periods, which suggests that wars lead to greater sourcing of existing technologies at the expenses of innovation (Mowery, 2010).

Second, we control for average body height (in cm). Height can be used as direct welfare measure of the population, but it can also reflect the calorie requirement of the population. This could potentially explain the significant findings for food innovation. Yet, including height as a control variable into our regression model does not change our main results (Table 8, Panel A2).

Third, we also test whether our results are driven by unusual military spending patterns in the exhibition years. Therefore, we relate innovation to lagged values of military spending (one, two, or three year lags). We also repeat our regressions with the average annual or cumulative military spending over the past three or five years (appropriately depreciated). Table 9 shows that food innovation is related to lagged, averaged and cumulative military spending, while the respective correlations with machinery innovation are only sporadically significant.

4.4 Alternative Samples

Next, we exclude specific countries or sample years in order to test the robustness of the results. Great Britain was the industrial leader in the 19^{th} century (Bairoch, 1972) and contributed the largest number of exhibits to both world exhibitions. Germany was fragmented into a number of independent states in 1851, while these states were united at the time of the second exhibition. Excluding all exhibits from either Great Britain or Germany does not alter our main finding (Table 8, Panels B1 and B2). Similarly, we confirm the robustness of the results when computing the marginal effects for both world exhibitions separately (Panels B3 and B4).

4.5 Alternative Empirical Specifications

Finally, we assess the sensitivity of the results with respect to alternative specifications: First, we use country fixed effects that capture systematic country-specific differences in the direction of technological change. For this purpose, we need to adjust the sample: German states are redefined in the boundaries of Germany in 1876 while Norway and Sweden are redefined according to the boundaries of 1851. The regressions include only country fixed effects and a year fixed effect for 1876. The estimated marginal effects in Panel C1 of Table 8 confirm the positive association between military spending and the probability to innovate in food processing. Second, we also test the robustness of our definition of military spending by employing an alternative multinomial logit regression using 'Log Military Expenditures' as main explanatory variable, instead of military expenditures divided by GDP (Panel C2). Again, the main finding of a positive correlation between military expenditures and food processing is robust. Both specification tests also suggest a positive relationship between military spending and machinery, although the correlation is not very stable across all robustness tests of Table 8. Third, we also test whether our results are driven by unusual military spending patterns in the exhibition years. Therefore, we relate innovation to lagged values of military spending (one, two, or three year lags). We also repeat our regressions with the average annual or cumulative military spending over the past three or five years. Table 9 shows that food innovation is related to lagged, averaged and cumulative military spending, while the respective correlations with machinery innovation are only sporadically significant.

5 Long-Term Relationship between Military and Innovation

Our results from World Exhibition data suggest that nations that spent more on the military were also more active in innovating in food processing in the 19^{th} century. Against the background of the supply chains of the time, it seems plausible that governmental demand for products of war logistics influenced the direction of innovation in the short-run. In this section we investigate whether this historically strong relationship bears any potential long-term implication. This perspective can complement the much broader literature on path dependency in innovation at the firm, industry or product level (e.g., Aghion et al., 2016; Augsdorfer, 2005; Patel & Pavitt, 1997). Our analysis is purely descriptive and, hence, possible correlations between contemporaneous innovation patterns with 19^{th} century military spending and innovation is certainly only suggestive. However, this exercise has the potential to unearth the country-specific evolution and long-term path dependency in innovation, a topic that has received limited attention to date.

For illustrative purposes, we exploit patent applications filed at the European

Patent Office (EPO) between the years 1990-2015. We assign all of these patent applications to countries using the inventors' country of residence as inferred from the geocoded address information in the OECD REGPAT Database. If a patent has multiple inventors, we assign equally weighted fractions. We classify all patents to food processing or food preservation according to the data description in the Online Appendix. Finally, we aggregate the data at the country level by simply counting the number of food processing patents and, as a subgroup, food preservation patents as well as the total number of patents. During the current observation period (1990-2015), the countries which can be geographically harmonized over 150 years (Austria & Hungary, Belgium, France, Germany, the Netherlands, UK, Sweden & Norway, Switzerland) had on average 111 889 patents; among these, there were 1915 food processing patents (1.7 percent) and 103 food preservation patents (0.1 percent).

First, we assess whether a historical focus on food is related to innovation in the food industry today. Our graphical results suggest that the historical relationship between the military and innovation has possibly long-term impacts on the direction of innovative activity: countries with a higher share of food innovation in the 19^{th} century (measured at the horizontal axis of Figure 7) tend to have a stronger focus on food processing innovation (left panel) and food preservation innovation (right panel) at the turn of the 21st century (measured at the vertical axis of Figure 7). With goodness-of-fit measures (R-squared) of 0.64 and 0.78 these highly significant correlations have substantial explanatory power and are consistent with long-time persistence in the direction of technological change (path dependency). Next, we look directly at the link between historical military spending and contemporaneous food innovation. Figure 8 (left panel) shows a weak and insignificant positive correlation between historical military spending and the current share of food processing in total innovation. Countries with higher military spending in the 19^{th} century have a higher share of food preservation innovation nowadays (Figure 8, right panel). The latter correlation is stronger but still imprecisely estimated. Our descriptive illustration indicates that innovation patterns in food are persistent and may partly be related to historical military demand in the 19th century.

6 Conclusion

This research investigates the relationship between military spending and the direction of technological change from a historical perspective. By combining military data of European countries with exhibition data from two famous world fairs in 1851 and 1876, we show that national military spending is positively associated with technological progress in food processing, and less so in machinery innovation. The importance of food processing is in line with historical accounts claiming that war success in the 19^{th} century was critically dependent on the ability to solve the logistical challenges of geographically expanding conflicts and growing army sizes. The quantitative results, therefore, support historical records which describe national food processing innovation as a complementary war technology in the 19^{th} century. Improvements in war logistics reflect a pivotal quality enhancement of the troops during the era of nation building. The insignificant relationship between military expenditures and national machinery innovation is plausible against the background of comparatively international supply structures for many weapons such as guns or cannons. As a cautious reminder, machinery may also be an overly broad product category to precisely capture weaponry innovation. Our comparative analysis is staged in the 19^{th} century innovation system in which private innovator-entrepreneurs supplied war equipment spurred by governmental demand and public innovation incentives (e.g., prize contests). Our findings therefore suggest a significant relationship between military spending and the direction of innovation even in the absence of public military R&D, and long before the emergence of the modern military-industrial complex. The results also suggest that the national innovation system responded stronger in competitive sectors dominated by national or subnational sourcing (such as food supply) compared to warfare sectors characterized by some Europe-wide dominant producers (such as gun or canon trade). Our research complements the discussion in the literature on whether the military sector was a driver of innovation in the 20^{th} century: for the 19^{th} century, we document a strong correlation between military spending and food innovation, which is in line with historical and qualitative evidence on the local, regional and national supply chains. Innovation in some markets might, hence, depend strongly on regional factors as suggested by the recently emerging literature hinting at a strong regional bias in innovation (Bernard et al., 2019; Danzer et al., 2020; Paci & Usai, 2000).

Moreover, we provide descriptive evidence that is consistent with food preservation having been an important technology for military logistics in the 19^{th} century with possible long-term implications for the geographic distribution of technological food innovation across European countries, as suggested by analyzing contemporary EPO patent data. However, more research is required to investigate the long-term path dependency of innovation patterns within and across countries.

Notes

1. The military has remained a tool for nation-building until present times (Alesina et al., 2020; Cáceres-Delpiano et al., 2021).

2. While medical innovation was potentially also important, the innovation process differed: Medical innovation was a consequence of war-related injuries (e.g., in the field of prosthetic devices, see Clemens and Rogers (2020), but the regular military budget devoted to medical devices was probably too small to stir innovation in general. Also, most armies featured only limited medical departments during peacetime, and called on civilian staff (e.g., surgeons) during wartime (Agarwal et al., 2021). As a consequence, medical instru-

ments or pharmacons are hardly found in the data used for the analysis.

3. Military engineering, guns and weapons are part of the 'machinery' class, which also includes vehicles, transportation and ship building. Many of the apparently civilian innovations in this class were highly relevant for the army and navy.

4. Medicine in the 19^{th} century made early advances around the Napoleonic wars and breakthrough discoveries during the last quarter of the century. While the former wave of innovations took place around 40 years before the first world exhibition, the most important discoveries, like Pasteur's and Koch's contributions to immunology and microbiology, took place after the second world exhibition. We searched the exhibition catalogues and found only very small numbers of exhibits related to pharmaceuticals, pharmacons (active ingredients) or medical instruments. We also find no correlation between military spending and the share of medical and scientific instruments.

5. Some recent cross-country evidence exists on the fiscal multiplier from military spending (Sheremirov & Spirovska, 2022).

6. The countries of our sample are: Austria, Baden, Bavaria, Belgium, Britain, Denmark, France, Hanover, Mecklenburg Schwerin, Netherlands, Norway, Prussia, Saxony, Sweden, Switzerland, and Württemberg.

7. Note that the German Empire was established as a united nation state in 1871 and these three member states are missing in the original data set.

8. The detailed data are from Moser (2011).

9. According to the German Report published by the governments of the Zollverein (German customs union) about the 1851 exhibition (Zollvereins-Regierungen, 1853) a large

fraction of food exhibits comprised processed and preserved food (e.g., solidified milk, meat-biscuits, dried and condensed vegetables, dried meat, pickles, preserved vegetables), sometimes of the experimental kind (e.g., meat in aluminium sulfate (!), sawdusk rusk, ship biscuits from wood shavings, sausage-like cakes of dried calf blood). Important contributions were tin cans for food preservation following the method by Appert, with different opening devices and of various content such as salmon, fried mutton, or veal roast with peas. The report mentions twelve English and fourteen French exhibitors in the area of meat preservation alone. It also explicitly highlights prize winning meat-biscuits for soldiers and preserved beef which was contracted by the English Navy. In the area of war machinery, a number of inventions surrounded improvements on the early Dreyse needle-gun system. Regarding war guns, the exhibition featured guns of several calibres. Important inventions relate to the shooting precision and shooting range of guns, the stability of gun barrels, the loading mechanism, the design and maneuverability of gun carriages, or the ignition powder, among many others. The exhibition catalogue of 1876 (Commission, 1876) lists exhibits without detailed descriptions; relevant food exhibits were ship biscuits and other conserved foods, milk powder, or conserved coffee. Important exhibits in war machinery were various types of new breech loading rifles, infantry rifles, express rifles, double guns, cartridges, percussion caps, ammunition, canons, gun barrels, and gun carriages.

10. The variable is from the World Bank's World Development Indicators. While it is a contemporary measure of arable land, Ashraf and Galor (2013) use it in regressions using historical data. Our key results are unaffected by the inclusion of this control variable.

11. We compute these predicted values from multinomial logit regressions holding all

other covariates constant.

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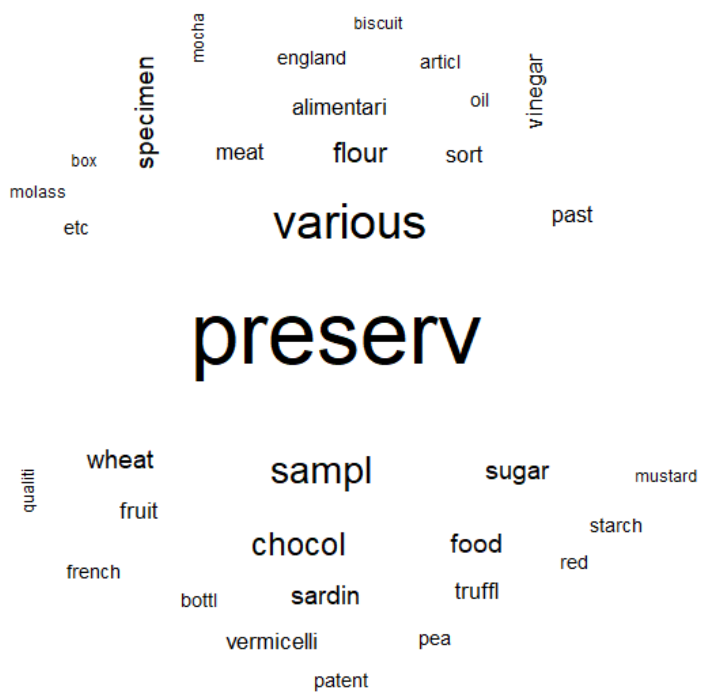
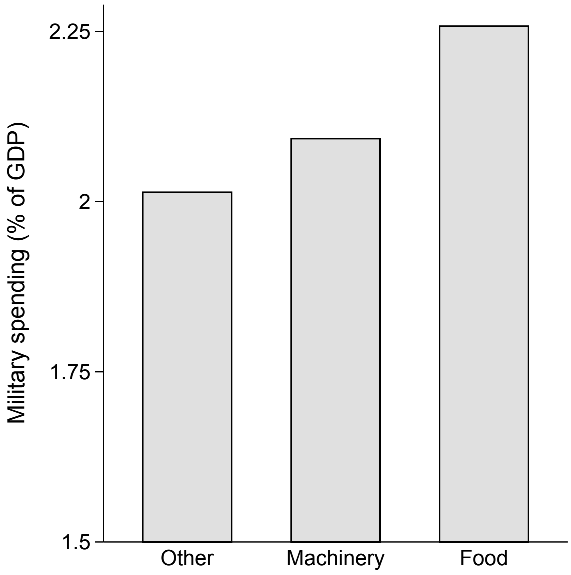
Figure 1: Word cloud



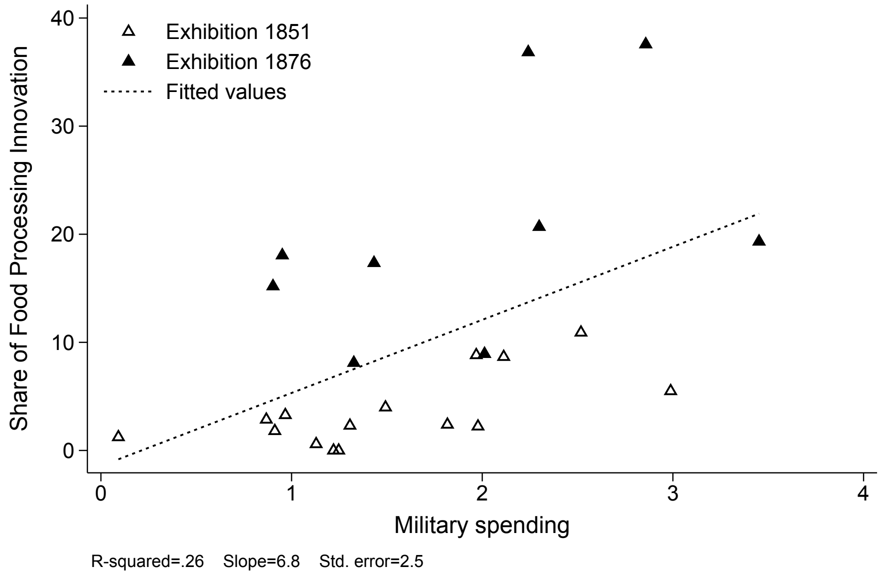
Notes: Word cloud plotting the frequency of word stems appearing in the descriptions of food processing exhibits from France in 1851. It is based on detailed exhibit-level data from Moser (2011). "preserv" is the most frequent word stem appearing in 32 % of the French food processing exhibits.

Figure 2: Average Military Spending by Technology Class



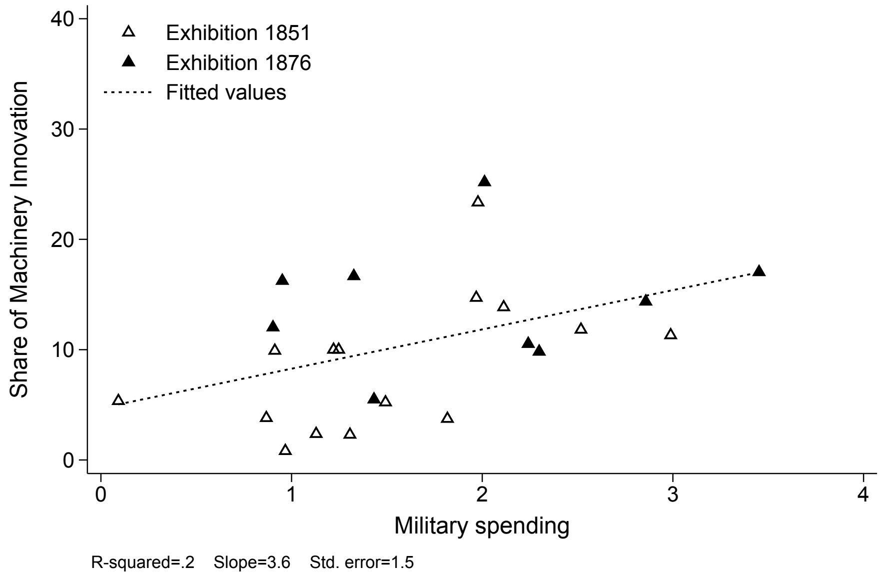
Notes: Average military spending (% of GDP) in the home-country of the inventors of exhibits of different technology classes.

Figure 3: Military Spending (% of GDP) and the Share of Food Processing Innovation



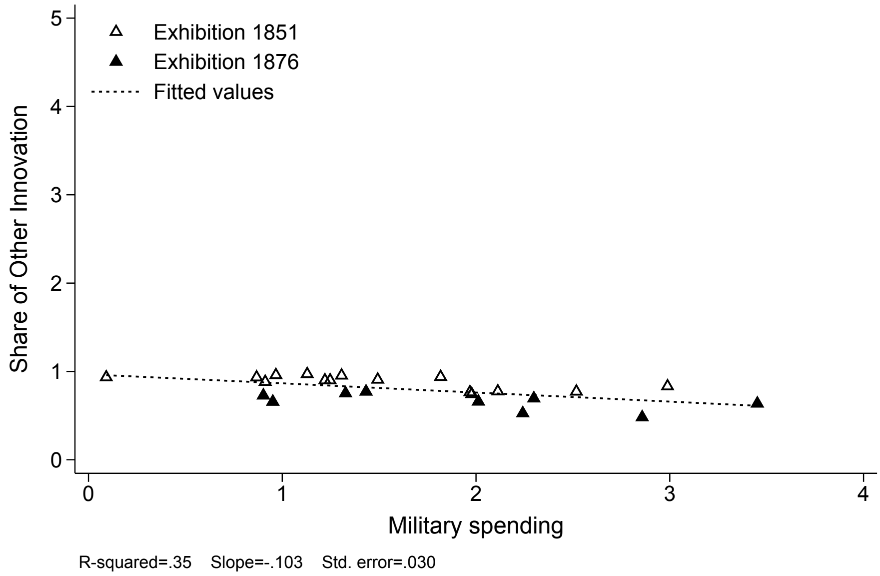
Notes: Scatterplot of military spending (% of GDP) and the country-level share of food processing innovation.

Figure 4: Military Spending (% of GDP) and the Share of Machinery Innovation



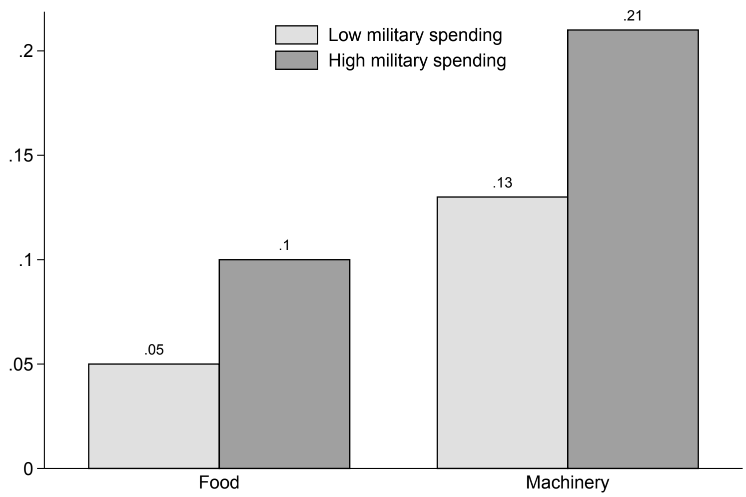
Notes: Scatterplot of military spending and the country-level share of machinery innovation.

Figure 5: Military Spending (% of GDP) and the Share of Other Innovation



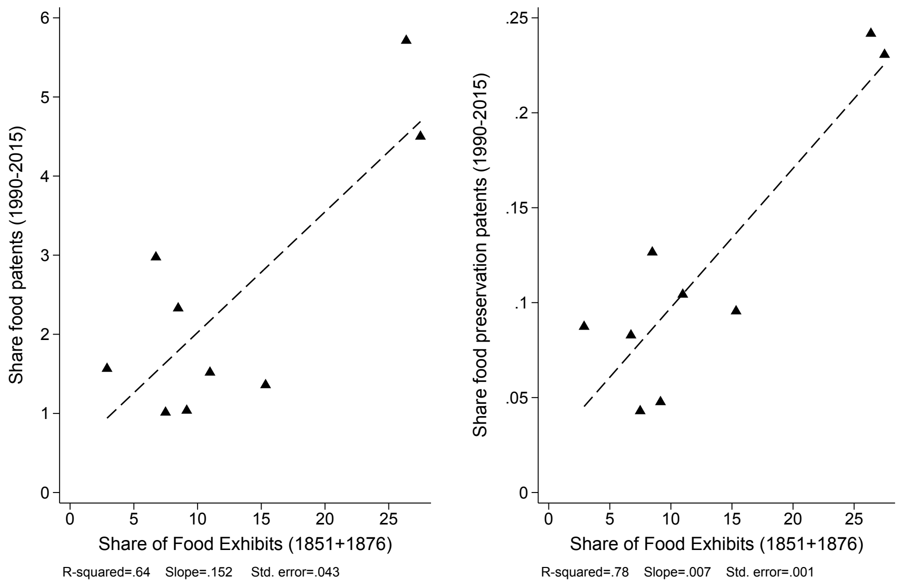
Notes: Scatterplot of military spending and the country-level share of other innovation.

Figure 6: Predicted Shares of Inventors' Choice of Technology Class



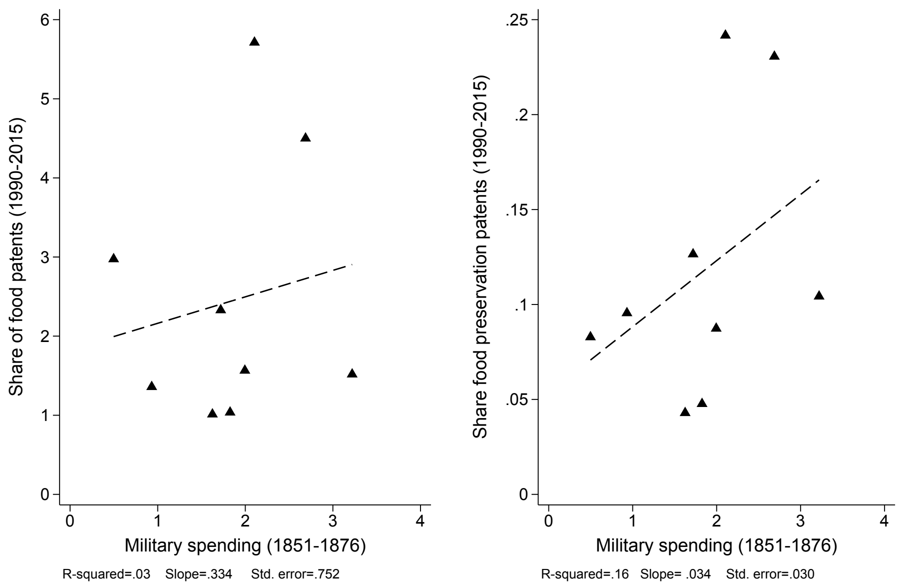
Notes: Figure compares the predicted share of inventors' choice of technology class when military spending is low (5 percentile) vs. high (95 percentile). Predicted values are calculated from multinomial logit regressions holding all other covariates constant.

Figure 7: Historical Food Innovation and Contemporary Food Innovation



Notes: Scatter plots of the historical share of food innovation at both world exhibitions in 1851 and 1876 and the share of food (preservation) patents filed at the European Patent Office between 1990 and 2015. See the Data Appendix for details on the construction of the contemporary innovation measures.

Figure 8: Historical Military Spending and Contemporary Food Innovation



Notes: Scatter plots of the average military spending in the years 1851 and 1876 and the share of food (preservation) patents filed at the European Patent Office between 1990 and 2015. See the Data Appendix for details on the construction of the contemporary innovation measures.

Table 1: Market Structures for Weaponry vs. Food in the 19^{th} century

Industry	Weaponry	Food
Demand in peacetime	Central government agencies (*national coordination offices*) with large but irregular orders	Often sub-national government agencies, e.g., *victualling offices* in each harbor
Supply	Modest number of global suppliers	Large number of mostly regional or national suppliers
Market structure	Equally powerful customer-seller relationship • Arms cartel or dominant producers on supply side • Various governments on demand side	Unequal power-relationship • Fierce competition on supply side • Monopsony on demand side; relations to the army administration led to preferential treatment (e.g. *Grüneberg's Erbstwurst*)
Firm strategy	• Serve global market to smooth demand • Produce different military and civilian products	• Produce similar military and civilian products to smooth demand
Exemplary firm	Krupp (Essen, Germany) • Global leader in guns in the late 19^{th} century • Railway business • Exports to British Royal Navy, Prussian Navy, Austro-Hungarian Navy, Spanish Navy, Russian Empire, Kingdom of Greece and Ottoman Empire, among others	Von Effner (Passau, Bavaria) • Producer of egg powder for the army: *„Militärconserve Nro. 1“* • Producer of egg powder for the civilian market
Well-known companies	• Austria: Steyr (rifles) • England: Armstrong (guns) • France: Creusot (guns) • Germany: Mauser (rifles) • US: Remington (guns)	• Belgium, England: Liebig's Extract of Meat Company • France: Chamborel • Germany: Knorr • Scotland: Johnston's ‚Fluid Beef‘ • Switzerland: Maggi

Notes: Grant (2007), Lehmann-Russbüldt (1929), Spiekermann (2018), Teuteberg (2007), Voit (1876), and Wehberg (1919).

Table 2: Summary Statistics

Variable	Mean	Std. Dev.	Min	Max	N
Technology Class					
Food processing	0.07	0.26	0.00	1.00	14456
Machinery	0.17	0.37	0.00	1.00	14456
Other	0.76	0.42	0.00	1.00	14456
Military Sector					
Military spending (in % of GDP)	2.04	0.67	0.09	3.45	14456
Military expenditure (in mio. USD 1990)	1090.51	723.38	4.81	2488.90	14456
Military personnel (in '000)	209.01	142.09	0.00	501.00	14456
Military expenditures per serviceman	4.93	1.66	1.23	8.26	14055
Controls					
Population (in '000)	23460.06	12467.56	539.00	43057.00	14456
GDP per capita	2.01	0.37	1.08	3.02	14456
Landlocked country	0.18	0.38	0.00	1.00	14456
Share arable land (in %)	25.77	7.57	5.01	53.76	14456
No patent laws	0.04	0.20	0.00	1.00	14456
Body height (in cm)	165.83	1.23	163.80	170.30	14456
Exhibition 1876	0.27	0.44	0.00	1.00	14456
Wars					
Any war (past 25 years)	0.40	0.49	0.00	1.00	14456

Notes: Summary statistics of the exhibit-level data set computed for the exhibition years 1851 and 1876. For a definition of variables and data sources see Table 10.

Table 3: Military Spending and Inventors' Choice of Technology Class

	1851 and 1876			1851	1876
Panel A: Food processing	(1)	(2)	(3)	(4)	(5)
Military spending	0.461***	0.470***	0.407***	0.780***	0.202***
	(0.144)	(0.140)	(0.143)	(0.227)	(0.069)
Exhibition 1876	1.773***	1.814***	1.798***		
	(0.185)	(0.143)	(0.133)		
Log Population	-0.256**	-0.252**	-0.330***	-0.414***	-0.308***
	(0.115)	(0.117)	(0.083)	(0.104)	(0.051)
GDP per capita		-0.338**	-0.393***	0.176	-0.476***
		(0.160)	(0.091)	(0.550)	(0.053)
Landlocked country			-0.501**	-0.168	-0.637***
			(0.211)	(0.478)	(0.166)
Share arable land			0.003	0.027	0.013***
			(0.006)	(0.022)	(0.004)
No patent laws			0.329	-0.288	0.579***
			(0.203)	(0.424)	(0.185)
Panel B: Machinery					
Military spending	-0.250	-0.010	0.278	0.317**	0.242**
	(0.241)	(0.222)	(0.175)	(0.133)	(0.101)
Exhibition 1876	0.173	-0.040	-0.077		
	(0.265)	(0.268)	(0.149)		
Log Population	0.524***	0.291**	0.025	-0.104	-0.133
	(0.184)	(0.126)	(0.116)	(0.187)	(0.086)
GDP per capita		0.900***	0.877***	2.084***	0.577***
		(0.334)	(0.211)	(0.702)	(0.070)
Landlocked country			-0.782**	-0.564	-0.703**
			(0.339)	(0.641)	(0.291)
Share arable land			-0.036**	0.002	-0.019***
			(0.015)	(0.039)	(0.007)
No patent laws			-0.234	-0.378	-0.303
			(0.361)	(0.536)	(0.295)
Observations	14456	14456	14456	10579	3877

Notes: Multinomial logit regressions estimated at the exhibit-level. Omitted category: other technologies. Standard errors clustered at the country-year level in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Table 4: Marginal Effects of Military Spending on Inventors' Choice of Technology Class

	Food	Machinery	Other
Average marginal effect	(1)	(2)	(3)
Military spending	0.022**	0.033	-0.055**
	(0.009)	(0.023)	(0.024)
Marginal effect at the mean	(4)	(5)	(6)
Military spending	0.017**	0.033	-0.050**
	(0.007)	(0.023)	(0.024)
Observations	14456	14456	14456

Notes: Marginal effects of military spending based on multinomial logit regressions from column 3 in Table 3. Standard errors clustered at the country-year level in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Table 5: Discussion: Military Personnel vs Capital Intensity of the Army

Panel A: Food	(1)	(2)	(3)	(4)
Log Military personnel	0.650	0.175		
	(0.410)	(0.282)		
Military expenditures per serviceman			0.673***	0.543***
			(0.124)	(0.167)
Exhibition 1876	1.803***	1.854***	2.298***	2.193***
	(0.176)	(0.140)	(0.155)	(0.132)
Log Population	-0.728	-0.277	-0.373***	-0.284***
	(0.514)	(0.339)	(0.096)	(0.078)
GDP per capita	-0.165	-0.407***	-2.731***	-2.392***
	(0.281)	(0.131)	(0.456)	(0.644)
Landlocked country		-0.293		-0.089
		(0.317)		(0.210)
Share arable land		0.014**		-0.000
		(0.005)		(0.007)
No patent laws		1.020***		0.697***
		(0.304)		(0.178)
Panel B: Machinery				
Log Military personnel	-0.690	-0.185		
	(0.552)	(0.573)		
Military expenditures per serviceman			0.248	0.385
			(0.163)	(0.308)
Exhibition 1876	0.105	0.008	0.077	0.227
	(0.274)	(0.169)	(0.200)	(0.236)
Log Population	0.971*	0.388	0.110	0.001
	(0.564)	(0.561)	(0.073)	(0.147)
GDP per capita	0.696*	0.728***	0.087	-0.577
	(0.372)	(0.274)	(0.536)	(1.199)
Landlocked country		-0.555		-0.525
		(0.439)		(0.354)
Share arable land		-0.025		-0.034**
		(0.016)		(0.014)
No patent laws		0.377		-0.098
		(0.477)		(0.422)
Observations	14055	14055	14055	14055

Notes: Multinomial logit regressions estimated at the exhibit-level. Omitted category: other technologies. Standard errors clustered at the country-year level in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Table 6: Marginal Effects: Military Personnel vs Capital Intensity of the Army

	Food	Machinery	Other
Log Military personnel	0.013	-0.027	0.014
	(0.016)	(0.076)	(0.078)
Military expenditures per serviceman	0.029***	0.046	-0.075*
	(0.008)	(0.040)	(0.045)
Observations	14055	14055	14055

Notes: Marginal effects based on multinomial logit regressions with a full set of controls from column 2 (Log Military personnel) and 4 (Military spending per serviceman) from Table 4. Standard errors clustered at the country-year level in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Table 7: Country-Level Analysis: Military Spending and Innovation

Dep. Var.:	Total Innovation		Food Processing				Machinery			
	Level		Share		Level		Share		Level	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Military spending	0.652**	0.291	6.761**	6.273**	1.213***	0.825**	3.561***	0.144	1.119***	0.442
	(0.276)	(0.238)	(2.583)	(2.485)	(0.254)	(0.320)	(0.967)	(2.086)	(0.330)	(0.314)
Exhibition 1876		-0.453		16.931***		1.176**		0.257		-0.269
		(0.483)		(2.673)		(0.471)		(2.517)		(0.611)
Log Population		1.037***		-3.018*		0.592**		0.789		1.084***
		(0.205)		(1.717)		(0.204)		(1.254)		(0.235)
GDP per capita		0.293		-1.880		0.037		6.879**		0.807
		(0.527)		(3.590)		(0.570)		(2.961)		(0.662)
Landlocked country		0.877*		-1.637		0.081		-6.303***		0.006
		(0.492)		(2.903)		(0.665)		(2.044)		(0.549)
Share arable land		-0.028*		0.004		-0.029		-0.039		-0.041**
		(0.016)		(0.114)		(0.022)		(0.099)		(0.019)
No patent laws		-0.066		1.548		-0.042		0.893		0.256
		(0.371)		(3.763)		(0.326)		(3.227)		(0.446)
Observations	24	24	24	24	22	22	24	24	24	24
R-squared	0.120	0.808	0.257	0.798	0.379	0.788	0.197	0.654	0.230	0.822

Notes: OLS regressions at the country-year level. Dependent variables: Column 1-2: number of total exhibits (entered in logs). Column 3-4: number of food processing exhibits divided by total number of exhibits. Column 5-6: number of food processing exhibits (entered in logs). Column 7-8: number of machinery exhibits divided by total number of exhibits. Column 9-10: number of machinery exhibits (entered in logs). Robust standard errors in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Table 8: Robustness: Marginal Effects of Military Spending on Inventors' Choice of Technology Class

	Food	Machinery	Other
Panel A: Additional control variables	(1)	(2)	(3)
A1: Accounting for wars (past 25 years)			
Military spending	0.022**	0.043***	-0.065***
	(0.009)	(0.010)	(0.015)
Observations	14456	14456	14456
A2: Accounting for body height			
Military spending	0.026***	0.030	-0.056***
	(0.008)	(0.022)	(0.022)
Observations	14456	14456	14456
Panel B: Alternative Samples			
B1: Excluding exhibits from Britain			
Military spending	0.029*	0.022	-0.052**
	(0.015)	(0.015)	(0.024)
Observations	7658	7658	7658
B2: Excluding exhibits from Germany			
Military spending	0.033***	-0.039	0.005
	(0.009)	(0.029)	(0.035)
Observations	12478	12478	12478
B3: Exhibits from 1851			
Military spending	0.022***	0.039**	-0.061***
	(0.007)	(0.018)	(0.019)
Observations	10579	10579	10579
B4: Exhibits from 1876			
Military spending	0.022*	0.026*	-0.048***
	(0.013)	(0.015)	(0.003)
Observations	3877	3877	3877
Panel C: Alternative Specifications			
C1: Country fixed effects			
Military spending	0.039**	0.076***	-0.115***
	(0.017)	(0.021)	(0.021)
Observations	14456	14456	14456
C2: Alternative Functional Form			
Log military expenditures	0.046***	0.055*	-0.101***
	(0.015)	(0.030)	(0.035)
Observations	14456	14456	14456

Notes: Marginal effects based on multinomial logit regressions with a full set of controls. In Panel C1 country fixed effects are included instead of the full set of country characteristics. Standard errors clustered at the country-year level in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Table 9: Robustness: Military Spending and Innovation - Different lag structures

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Food							
Military spending t-1	0.308***						
	(0.089)						
Military spending t-2		0.247***					
		(0.081)					
Military spending t-3			0.289***				
			(0.080)				
Average military spending t-3 till t				0.322***			
				(0.093)			
Average military spending t-5 till t					0.223***		
					(0.079)		
Cumulative military spending t-3 till t						0.080***	
						(0.023)	
Cumulative military spending t-5 till t							0.037***
							(0.013)
Machinery							
Military spending t-1	0.213						
	(0.156)						
Military spending t-2		0.078					
		(0.164)					
Military spending t-3			0.249*				
			(0.128)				
Average military spending t-3 till t				0.204			
				(0.155)			
Average military spending t-5 till t					0.253**		
					(0.110)		
Cumulative military spending t-3 till t						0.051	
						(0.039)	
Cumulative military spending t-5 till t							0.042**
							(0.018)
Observations	14456	14456	14456	14456	14456	14456	14456

Notes: Multinomial logit regressions estimated at the exhibit-level. Omitted category: other technologies. Standard errors clustered at the country-year level in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Online Appendix

Table 10: Variable Definitions

Variable	Description and Source
Military Sector and Wars	
Military spending	Military expenditures in % of GDP. Military spending: National Material Capabilities (v5.0) from the Correlates of War Project. GDP: Maddison (1995, 2001).
Military expenditures	Military expenditures in million 1990 dollars. National Material Capabilities (v5.0) from the Correlates of War Project.
Military personnel	Military personnel in thousand. National Material Capabilities (v5.0) from the Correlates of War Project.
Military expenditures per serviceman	Military expenditures per serviceman in thousand 1990 dollars. National Material Capabilities (v5.0) from the Correlates of War Project.
Any war (past 25 years)	Binary indicator equal to 1 if a country was involved in an inter state war 25 years before the exhibition. Inter-State War data set (v4.0) from the Correlates of War Project.
Country Characteristics	
Population	Population in thousand. National Material Capabilities (v5.0) from the Correlates of War Project.
GDP per capita	GDP per capita in thousand 1990 dollars. Maddison (1995, 2001).
Landlocked country	Binary indicator equal to 1 if a country is landlocked.
Share arable land	The percentage of a country's total land area that is arable. Oded and Galor (2013), originally based on data from the World Bank's World Development Indicators.
No patent laws	Binary indicator equal to 1 if a country has not a patent system. Lerner (2000) and Coryton (1855).
Body height	Average height in cm. Baten and Blum (2015).

Table 11: Summary Statistics at the Country-Level

Variable	Mean	Std. Dev.	Min	Max	N
Innovation					
Food processing exhibits / exhibits	9.86	10.63	0.00	37.57	24
Food processing exhibits	42.63	53.27	0.00	194.00	24
Non-food processing exhibits	559.71	1204.08	10.00	5979.00	24
Machinery exhibits / exhibits	10.66	6.40	0.82	25.18	24
Machinery exhibits	99.71	288.29	1.00	1428.00	24
Non-machinery exhibits	502.63	949.90	9.00	4687.00	24
Total exhibits	602.33	1232.52	10.00	6115.00	24
Military Sector					
Military spending (in % of GDP)	1.67	0.80	0.09	3.45	24
Military expenditures (in mio. USD 1990)	462.34	749.22	4.81	2488.90	24
Military personnel (in '000)	100.25	146.19	0.00	501.00	24
Military expenditures per serviceman	3.56	1.96	1.23	8.26	24
Controls					
Population (in '000)	10449.38	13568.26	539.00	43057.00	24
GDP per capita	1.81	0.46	1.08	3.02	24
Landlocked country	0.42	0.50	0.00	1.00	24
Share arable land (in %)	27.72	12.54	5.01	53.76	24
No patent laws	0.21	0.41	0.00	1.00	24
Body height (in cm)	165.84	1.77	163.80	170.30	24
Exhibition 1876	0.38	0.49	0.00	1.00	24
Wars					
Any war (past 25 years)	0.38	0.49	0.00	1.00	24

Notes: Summary statistics of the country-level data set. For a definition of variables and data sources see Table 10.

Table 12: Military Spending and Inventors' Choice of Technology Class: Using a Narrow Definition of Weaponry

	1851 and 1876			1851	1876
Panel A: Food processing	(1)	(2)	(3)	(4)	(5)
Military spending	0.493***	0.484***	0.381***	0.767***	0.159*
	(0.148)	(0.141)	(0.146)	(0.239)	(0.082)
Centennial Exhibition	1.741***	1.811***	1.804***		
	(0.208)	(0.143)	(0.134)		
Log Population	-0.334***	-0.304***	-0.330***	-0.393***	-0.289***
	(0.118)	(0.114)	(0.084)	(0.126)	(0.061)
GDP per capita		-0.501***	-0.556***	-0.112	-0.573***
		(0.160)	(0.104)	(0.551)	(0.062)
Landlocked			-0.377*	-0.070	-0.525***
			(0.195)	(0.479)	(0.195)
Share arable land			0.007	0.026	0.016***
			(0.006)	(0.021)	(0.004)
No patent laws			0.369*	-0.244	0.616***
			(0.202)	(0.474)	(0.225)
Panel B: Weapons					
Military spending	-0.275	-0.165	-0.176	-0.142	-0.593**
	(0.234)	(0.235)	(0.283)	(0.336)	(0.283)
Centennial Exhibition	-0.246	-0.411	-0.424*		
	(0.385)	(0.272)	(0.253)		
Log Population	-0.073	-0.224	-0.269	0.037	-0.238*
	(0.189)	(0.183)	(0.228)	(0.398)	(0.142)
GDP per capita		0.669*	0.760**	-0.190	1.424***
		(0.353)	(0.370)	(0.470)	(0.071)
Landlocked			0.035	0.425	-0.739*
			(0.420)	(0.634)	(0.401)
Share arable land			-0.006	-0.014	-0.015
			(0.017)	(0.014)	(0.022)
No patent laws			-0.558*	-0.181	-0.246
			(0.322)	(0.530)	(0.333)
Observations	14456	14456	14456	10579	3877

Notes: Multinomial logit regressions estimated at the exhibit-level. Omitted category: other technologies. Standard errors clustered at the country-year level in parentheses. Significance levels: * $p<0.10$, ** $p<0.05$,*** $p<0.01$. For a definition of variables and data sources see Table 10.

Table 13: Country-Level Analysis: P-values of permutation tests

Dep. Var.:	Food processing	Machinery
Permutation test 1	0.063	0.461
Permutation test 2	0.003	0.452
Permutation test 3	0.086	0.933
Observations	24	24

Notes: Permutation tests for the country-year level data sets. Permutation test 1 permutes y (see column head) using 1000 permutations. Permutation test 2 permutes x (military spending) across countries and years using 1000 permutations. Permutation test 3 simulates military spending with 2000 permutations, before permuting x 1000 times. Dependent variable: Column 1: number of food processing exhibits divided by total number of exhibits. Column 2: number of machinery exhibits divided by total number of exhibits.

Table 14: Country-Level Analysis: Military Personnel vs. Capital Intensity of the Army

Dep. Var.:	Total Innovation		Food Processing				Machinery			
	Level		Share		Level		Share		Level	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Log military personnel	-0.364		2.410		-0.272		-2.765		-0.777	
	(0.662)		(4.546)		(0.871)		(2.682)		(0.689)	
M. spending p. serviceman		0.356		5.320***		0.716***		0.241		0.501*
		(0.206)		(1.102)		(0.217)		(1.529)		(0.262)
Centennial Exhibition	-0.391	-0.231	18.076***	20.762***	1.117*	1.533***	-0.796	-0.779	-0.284	-0.067
	(0.543)	(0.562)	(3.086)	(2.368)	(0.520)	(0.477)	(2.527)	(2.502)	(0.664)	(0.669)
Log Population	1.527*	1.029***	-3.812	-2.897**	1.098	0.699***	3.965	0.948	2.061**	1.080***
	(0.809)	(0.188)	(5.230)	(1.189)	(0.963)	(0.188)	(3.298)	(0.977)	(0.810)	(0.206)
GDP per capita	0.336	-0.914	-0.131	-19.711***	0.356	-2.253**	7.463**	6.905	0.920	-0.809
	(0.567)	(0.876)	(5.116)	(5.707)	(0.718)	(0.962)	(3.018)	(5.900)	(0.713)	(1.196)
Landlocked	0.895	1.137**	-4.032	0.229	-0.190	0.580	-5.440**	-5.484**	0.016	0.334
	(0.546)	(0.520)	(4.263)	(2.529)	(0.708)	(0.661)	(1.904)	(2.528)	(0.564)	(0.487)
Share arable land	-0.021	-0.031	0.158	0.060	-0.009	-0.026	-0.050	-0.069	-0.029	-0.043*
	(0.018)	(0.018)	(0.138)	(0.089)	(0.025)	(0.025)	(0.086)	(0.092)	(0.021)	(0.021)
No patent laws	0.184	0.011	1.658	-0.127	0.264	0.122	2.976	2.602	0.613	0.342
	(0.675)	(0.477)	(8.774)	(6.943)	(0.591)	(0.325)	(4.356)	(4.580)	(0.669)	(0.581)
Observations	22	22	22	22	20	20	22	22	22	22
R-squared	0.805	0.828	0.703	0.822	0.710	0.797	0.695	0.684	0.823	0.846

Notes: OLS regressions at the country-year level. Dependent variables: Column 1-2: number of total exhibits (entered in logs). Column 3-4: number of food processing exhibits divided by total number of exhibits. Column 5-6: number of food processing exhibits (entered in logs). Column 7-8: number of machinery exhibits divided by total number of exhibits. Column 9-10: number of machinery exhibits (entered in logs). Robust standard errors in parentheses. Significance levels: * p<0.10, ** p<0.05,*** p<0.01. For a definition of variables and data sources see Table 10.

Data Description

Exhibition Data. Regarding the year 1876, we merge the countries Norway and Sweden into one country "Kingdom of Norway and Sweden" to make the exhibition data compatible with the military data. Using the official exhibition catalogue for 1851, we complement the exhibition data from Moser (2005) with innovation data for three German states: 'Baden', 'Mecklenburg Schwerin' and 'Hanover'. For this purpose, we have manually assigned each exhibit into one of the three technology classes using the description of the exhibits.

Military data. We directly match the military data to the exhibition data using information on countries and years. Regarding Austria, we approximate military expenditures (personnel) by multiplying the military expenditures (personnel) of Austria-Hungary with the corresponding population share. Regarding the military expenditures of Switzerland in 1851, we use the value of the year 1853 because information on military expenditures is only available from 1853 onwards (The Swiss Confederation was established only in 1848).

Other country characteristics. Since GDP data is only available for the whole of Germany in 1851, we approximate the GDP of the German states (Baden, Bavaria, Hanover, Mecklenburg Schwerin, Wurttemberg) by multiplying population figures from the Correlates of War Project with German GDP per capita as reported in Maddison (1995,2002). We impute the share of arable land and average height for the German states using the values from Germany. Given that historical average heights were very similar in Norway and Sweden, we use the value from Sweden for the Kingdom of Norway and Sweden. Regarding average height in Switzerland in 1851, we use the corresponding value from 1830.

Contemporary Patent Data. For the construction of measures on contemporary innovation in food processing, we utilise patent applications filed at the European Patent Office between 1990 and 2015. We assign patent applications to countries using the inventors' country of residence as inferred from the geocoded address information in the OECD REGPAT Database. If a patent has multiple inventors, we assign equally weighted fractions to the inventor's country of residence. We classify a patent application into food processing if one of the associated IPC classes corresponds to either A21 (baking; equipment for making or processing doughs;

doughs for baking), A22 (butchering; meat treatment; processing poultry or fish) or A23 (foods or foodstuffs; their treatment, not covered by other classes). We classify a patent application into food preservation if it contains the IPC class A23B (preserving, e.g., by canning, meat, fish, eggs, fruit, vegetables, edible seeds; chemical ripening of fruit or vegetables; preserved, ripened, or canned products). We aggregate the patent data to the country level by counting the number of food processing patents and the total number of patents.