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"WAR, WHAT IS IT GOOD FOR?" THE INDUSTRIAL REVOLUTION!

Stephen D. Billington (Queen's University Belfast)

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QUEEN'S UNIVERSITY CENTRE FOR ECONOMIC HISTORY
Queen's University Belfast
185 Stranmillis Road
Belfast BT9 5EE

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Stephen D. Billington[‡]

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Abstract

Did the French Revolutionary and Napoleonic wars contribute to the Industrial Revolution? Recent scholarship argues warfare was an important factor in explaining Britain's industrialisation, by encouraging the invention and diffusion of key technologies with military applications. I re-examine this hypothesis by analysing the patenting of military inventions and inventions considered to be economically valuable during the Industrial Revolution. I find war led to a permanent increase in the rate of military and valuable patenting. War likely created a demand for superior military technologies, while increased wartime production led to demands for more valuable technologies, which both stimulated the Industrial Revolution.

Keywords: Industrial Revolution, Patents, War

JEL Codes: N43, N74, O31

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[‡]Queen's University Belfast. Email: sbillington01@qub.ac.uk.

1 Introduction

Britain industrialised amidst the French Revolutionary and Napoleonic wars (c.1793–1815). Warfare cannot, therefore, be ignored in explanations for the Industrial Revolution (O'Brien, 2017), and recent scholarship draws a direct causal link between Britain's military engagements and industrialisation (Satia, 2018; Juhász, 2018). Inventive behaviour was an essential component of Britain's Industrial Revolution (Allen, 2009; Mokyr, 2009). I investigate warfare's role in encouraging this invention by analysing all of Britain's patents during the Industrial Revolution period. I find war led to an increase in economically valuable patenting and this increase was permanent. In particular, war led to increases in military patenting. Finally, invasion fears discouraged patenting behaviour for economically valuable inventions. Overall, my results suggest war, when it was going well for British forces, stimulated the Industrial Revolution.

My study relates to a growing literature linking warfare and industrialisation. This literature focuses on the crowding-out of private investment (Ashton, 1960; Williamson, 1984); international trade (O'Rourke, 2006); and the link with industrialisation and innovation (Hanlon, 2015; O'Brien, 2017; Satia, 2018; Juhász, 2018). I contribute by showing war coincided with an acceleration in the patenting of military and economically valuable inventions. This paper is closely related to Khan (2015), who observes patenting behaviour during the US Civil war. She finds that US "great inventors" (who held multiple patents) switched into the market for military technologies. The present study finds a different effect: British inventors who held multiple patents increased only their patenting of economically valuable inventions.

2 Data

My data constitute the entire population of British patents granted to British inventors during the Industrial Revolution, collected from Woodcroft (1854) and Bottomley (2014a). This section details variables I construct for the present analysis.

It is important to note not all inventions are patentable, and not all inventors obtain

patents. During the Industrial Revolution most inventions which could be patented are thought to have been patented (Sullivan, 1989), as contemporaries viewed the secrecy alternative as less viable due to reverse-engineering (Dutton, 1984). Britain's patent data contain most key inventions associated with the Industrial Revolution (Bottomley, 2014b); Watt's separate condenser, Hargreaves' spinning jenny, Kay's flying shuttle, Arkwright's water frame, Cartwright's power loom, and Cort's puddling process were all patented. The patent data reasonably approximate British inventive activity.

2.1 Patent Classes

The propensity to patent varies across technology groups (Moser, 2005). Controlling for technology groups mitigates this bias during statistical analysis. However, the choice of taxonomy can influence conclusions drawn from patent data (Billington and Hanna, 2018). To overcome this problem, I adopt a machine learning approach and patent schema of Billington and Hanna (2018). Their method relies on identifying commonly appearing words in patent titles to cluster patents of a similar nature into topics. Each topic is assigned to one of 19 patent classes. Classes are then assigned to patents through their highest scoring topic, which is my control for technology groups in all regressions.

2.2 High-value Patents

Economically or technically valuable inventions are identified using the Woodcroft Reference Index (WRI), pioneered by Nuvolari and Tartari (2011). A patent's value is inferred from the relative number of references – weighted by cohort – received in the contemporary scientific and trade literature. However, warfare could have affected the real value of patented inventions, either due to rising inflation (making patenting cheaper, as application fees remained fixed in nominal terms) or increased uncertainty (making patenting riskier), factors not captured by these references.

Instead, I construct quartile bins from the WRI to identify valuable patents between 1617 and 1852, the period of Britain's first unreformed patent system. This creates the following variables: high-value (the top 25%), mid-value (the top 25-50%), low-value

(the bottom 25-50%), and bottom-value (the bottom 25%). I assume very valuable patents received a disproportionately high number of references; the efficacy of warfare in encouraging valuable patenting is determined by counting high-value patents for any given period.

2.3 Military Patents

During the Napoleonic wars (1803–1815) a "Navy Clause" was inserted into patent applications of military-related inventions (Bottomley, 2014b); it was introduced in the prior conflict, but rarely used. This Navy Clause resulted in a transaction between the inventor and the British government: the government had the right to force the inventor to license their patented invention at reasonable prices (Bottomley, 2014b). The Clause could have affected the patenting behaviour of military inventors.

To identify military-related patents for the remainder of my dataset, I use a logistic regression (LR) machine learning model to predict which patents are likely to have been military-related, based on Navy Clause patent titles. Navy Clause patents are randomly divided into "test" and "training" data. I derive the LR model from the training dataset, which was 87% accurate at identifying Navy Clause patents. Then, I apply the LR model to the test data, which predicted 91% of Navy Clause patents. Similar accuracy scores are obtained using alternate techniques, such as naive Bayes classifiers, support vector machines, and k-nearest neighbour clustering. I choose the LR model because it produced fewer errors. Finally, I apply the LR model to my entire dataset. Relevant military patents are termed "predicted-military". Figure 1 graphs the share of predicted-military and Navy Clause patents granted each year during the Industrial Revolution; war is weakly correlated with military patenting.

2.4 Invasion Fear

War may be associated with uncertainty, potentially discouraging inventors from inventing or patenting. To proxy uncertainty, I observe when invasion fears ran high. There were three unsuccessful French invasions during the French Revolutionary wars

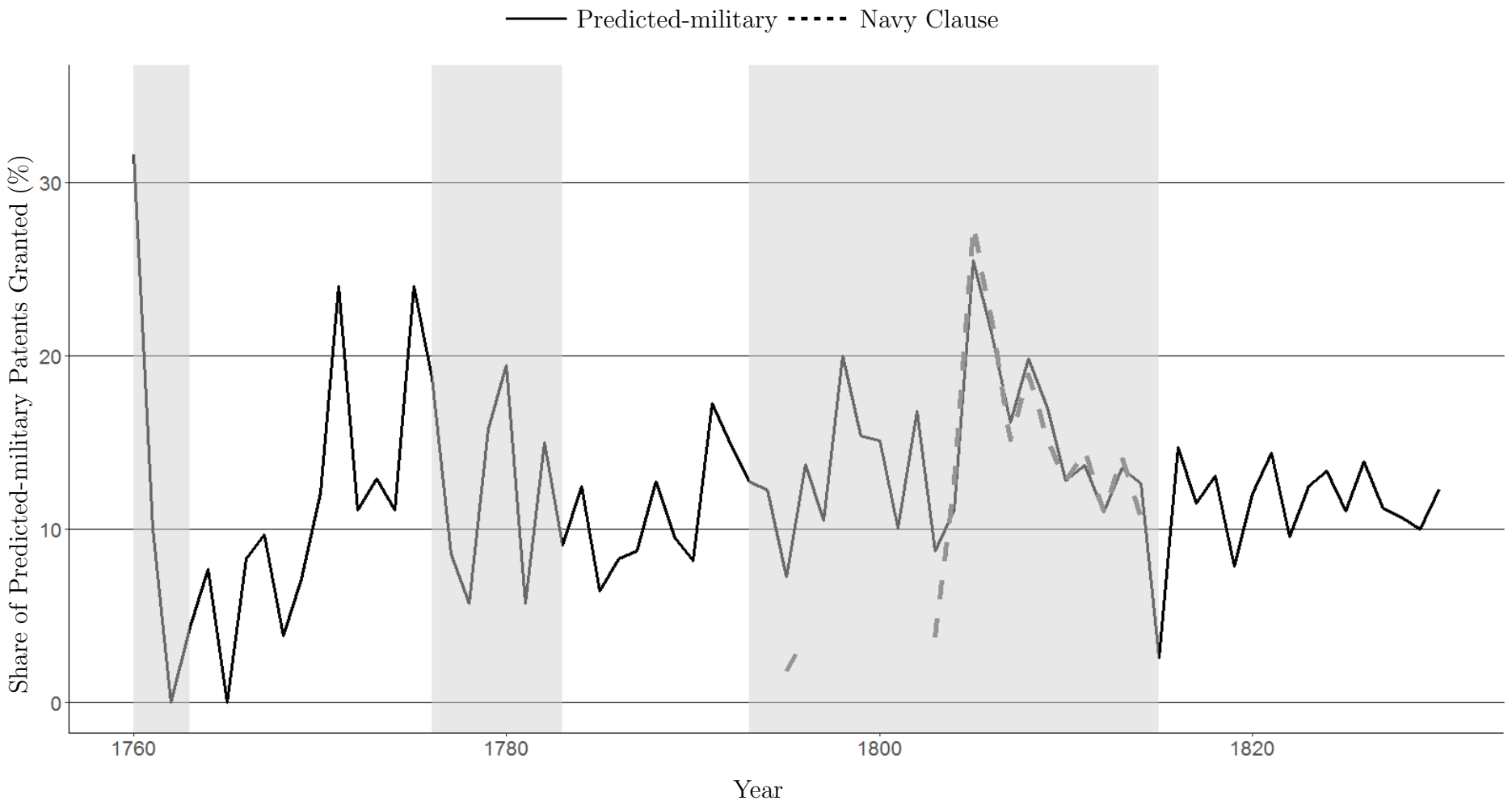

Figure 1: Time Series of Predicted-military and Navy Clause Patents Granted, 1760–1830

Source: Author's calculations using data from Woodcroft (1854)

Notes: Shaded areas represent periods of warfare. The first shaded area is the Seven Years War (1756–1763); the next is the US Revolutionary War (1775–1783); the last constitutes the French Revolutionary and Napoleonic Wars (1793–1815).

(1793–1802): in 1796 the French approached Ireland; in 1797 they landed in Wales; and in 1798 they landed in Ireland. The latter two were swiftly defeated (Knight, 2013).

The Napoleonic wars reignited invasion fears. Between 1803 and 1805, Napoleon assembled his army to invade Britain (Hall, 1992). However, Napoleon's attention shifted to Austria in August 1805; the invasion was abandoned. Then, in October, Britain defeated French naval forces at Trafalgar, mitigating invasion fears once and for all (Knight, 2013).

I construct a dummy variable – "Invasion" – for those months of heightened invasion fears: December 1796 – March 1797; May 1798 – October 1798; 1803 – October 1805. I assume uncertainty prevailed for at least one additional month (except after Trafalgar), as invasion fears are unlikely to dissipate instantaneously.

2.5 Serial Patentees

Inventors may have switched their efforts away from economically valuable invention toward military inventions during the wars (Khan, 2015). To test this, I observe inventors who held multiple patents to examine their response to periods of war. I construct a dummy variable for "Serial Patentees" who held three or more patents during their careers, based on their listed name, location, and occupation. Inventors with common names (e.g. Smith) are omitted. Similarly, patent agents are excluded as they often held dozens of patents, both for themselves and their clients (Bottomley, 2014b).

3 Empirical Strategy

To test how warfare affected patenting, I use the following probit model specification:

$$P(y_{it}|A_t, X_{it}) = \Phi(\beta_1 A_t + \beta X_{it}) \tag{1}$$

The dependent variable, y, is a dummy indicating either a valuable patent or a military patent belonging to inventor i at time t. The set of explanatory variables, A, include wartime dummies, and a dummy to capture invasion fears. The control variables, X,

constitute: a five-year inflation average; whether the inventor possessed any prior patents; occupation; whether the invention matches the inventor's occupation (to control for incremental innovations); the invention's technology class; the inventor's country of residence within Britain; and whether the invention is labour- or capital-saving (labour-saving may have been more valuable). Standard errors are clustered by year, and all results reported are marginal effects at the means.

4 Results

4.1 All Patentees

Table 1 reports my key probit regression results. The first half of the table reports the association between warfare and military patenting. Should warfare have promoted industrialisation through invention, I would expect to observe increased military-related patenting. The results, at first, suggest limited change in military patenting (column 1). The Napoleonic wars (column 2) show no change in military patenting compared to the earlier French Revolutionary wars. The "pre-war" period (column 3) shows military patenting increased during the French wars; inventors may have been encouraged by the greater scale of later conflicts, or the active use of the Navy Clause. The "post-war" period (column 4) shows no further change in military patenting, implying the French wars led to a one-time permanent acceleration in military patenting. Finally, invasion fears had no distinguishable effect on military patenting.

The second half of Table 1 reports the results for high-value patents. Here, I expect to observe a positive effect for wartime dummies, which would support the argument war led to increased invention. The results initially suggest war *decreased* high-value patenting by 10-30% (column 5), but this is biased by post-war observations. The Napoleonic wars saw a 20% increase in high-value patents compared to the prior conflict (column 6). The pre-war period (column 7) suggests the combined French wars increased high-value patenting. The post-war period (column 8) shows the rate of high-value patenting further increased. Finally, the invasion metric is negative and statistically significant.

Table 1: Probit regression results showing the relationship between military patenting, high-value patenting and periods of warfare for all patentees

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted-military				High-value			
Seven Years War	0.024		0.018		-0.295**		-0.186*	
	(0.083)		(0.080)		(0.128)		(0.097)	
US Revolutionary War	-0.004		0.005		-0.200***		-0.060	
	(0.023)		(0.024)		(0.068)		(0.047)	
French Revolutionary War	0.017*		0.055**	0.005	-0.132***		0.125***	-0.257***
	(0.010)		(0.025)	(0.012)	(0.046)		(0.036)	(0.057)
Napoleonic War	0.024	0.041	0.091**	0.026	-0.102**	0.204***	0.272***	-0.042
	(0.017)	(0.031)	(0.042)	(0.019)	(0.048)	(0.031)	(0.045)	(0.049)
Invasion		-0.020	-0.019	-0.008		-0.079***	-0.054**	-0.080*
		(0.032)	(0.025)	(0.026)		(0.029)	(0.023)	(0.047)
Predicted-military					-0.058***	-0.080**	-0.054**	-0.075***
					(0.018)	(0.031)	(0.021)	(0.023)
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Technology	Y	Y	Y	Y	Y	Y	Y	Y
Period	1760–1830	1793–1815	1760–1815	1793–1830	1760–1830	1793–1815	1760–1815	1793–1830
Observations	5,512	1,960	3,270	4,253	5,546	2,102	3,282	4,366
Pseudo R-Squared	0.131	0.120	0.117	0.144	0.101	0.059	0.130	0.05

Notes: Table reports probit regression results. Coefficients are marginal effects at the means. For columns 1-4, the dependent variable is a dummy for military patents. For columns 5-8, the dependent variable is a dummy for high-value patents, defined using the top 25% WRI. Invasion is a dummy to proxy for uncertainty effects. Columns 1 and 5 observe the period 1760–1830. Columns 2 and 6 observe the period 1793–1815. Columns 3 and 7 observe the period 1784–1815. Columns 4 and 8 observe the period 1793–1830. Standard errors clustered by year ***p<0.001, **p<0.05, *p<0.1.
Source: Author's calculations using data from Woodcroft (1854) and Nuvolari and Tartari (2011)

Table 2: Probit regression results showing the relationship between military patenting, high-value patenting and periods of warfare for only serial patentees

VARIABLES	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted-military				High-value			
Seven Years War	-0.111		-0.122					
	(0.134)		(0.135)					
US Revolutionary War	-0.089**		-0.088*		-0.100		0.022	
	(0.044)		(0.050)		(0.113)		(0.097)	
French Revolutionary War	0.012		0.037	0.014	-0.149***		0.123*	-0.235***
	(0.015)		(0.041)	(0.018)	(0.048)		(0.066)	(0.061)
Napoleonic War	0.016	0.042	0.072	0.009	-0.091*	0.222***	0.304***	-0.039
	(0.025)	(0.049)	(0.067)	(0.028)	(0.049)	(0.054)	(0.091)	(0.048)
Invasion		-0.022	-0.022	0.001		-0.086*	-0.062	-0.055
		(0.047)	(0.037)	(0.032)		(0.051)	(0.047)	(0.063)
Predicted-military					-0.076**	-0.075	-0.075	-0.073*
					(0.033)	(0.063)	(0.046)	(0.038)
Controls	Y	Y	Y	Y	Y	Y	Y	Y
Technology	Y	Y	Y	Y	Y	Y	Y	Y
Period	1760–1830	1793–1815	1760–1815	1793–1830	1760–1830	1793–1815	1760–1815	1793–1830
Observations	2,082	732	1,153	1,738	2,137	840	1,180	1,797
Pseudo R-Squared	0.147	0.138	0.132	0.171	0.089	0.075	0.118	0.058

Notes: Table reports probit regression results for serial patentees. See Table 1 for notes. Standard errors clustered by year ***p<0.001, **p<0.05, *p<0.1.
Source: *ibid*

4.2 Serial Patentees

To test whether inventors switched their activities toward or away from the war effort, Table 2 presents probit results for Serial Patentees; the control variables remain unchanged from Table 1. The first half of Table 2 presents the results for military patents. Serial patentees appear largely unaffected by war and do not shift towards patenting military inventions. This implies the variation observed in Table 1 is potentially driven by new patentees, encouraged to invent by the demand for war-related goods.

The second half of Table 2 examines high-value patents. Serial patentees patented fewer high-value inventions during war when observing the entire period (column 5). Contrasting the period of the French wars (column 6), the Napoleonic period saw a 22% increase in high-value patents. The pre-war period (column 7) suggests the French wars significantly increased high-value patenting, while the post-war period (column 8) reports high-value patenting had been permanently increased by the Napoleonic wars. The invasion dummy is negative but only significant in columns 5 and 8 – when the post-war observations are included.

5 Conclusion

My results show a sustained increase in the patenting of military and economically valuable inventions. This suggests two probable conclusions regarding invention during the Industrial Revolution: the British government demanded superior military technologies, and rising wartime production necessitated the development of more valuable technologies.

Military patenting increased during the French wars, and did not decline after the wars concluded in 1815. This result is likely driven by new inventors entering the patent system. The French wars were considerably greater in scale than prior conflicts, and the British government was increasingly subcontracting for military innovations (Satia, 2018). The Navy Clause is likely a direct result of the subcontracting behaviour, and may

have encouraged military patenting. This is the most likely explanation for the sustained increase in military patenting.

The rise in high-value patenting coincides with the French wars, and the post-war peace. Although initial results show a negative association with war, high-value patenting did increase. The Napoleonic wars induced more high-value patenting than the prior conflict, presumably because this war was the greatest conflict Europe had seen. After the wars concluded, high-value patenting further increased, which suggests the wars permanently accelerated British patenting, and presumably inventive, behaviour. The war also supports the demand-side explanation of the Industrial Revolution (Allen, 2009), as inventors responded to the economic demands created by war.

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