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Military Technology and Sample Selection Bias

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Abstract

Military enlistment is highly selective for reasons of both labor demand and supply. An early-twentieth-century evolution of military technology that shifted the demand for workers of different stature illustrates the importance of labor demand beyond the commonly discussed influences originating with labor supply. English-born soldiers in the Anglo-Boer War (1899–1902) were taller, on average, than those of World War I (1914–18), yet these differences cannot be attributed to standard of living or business cycle influences on the labor market. Rather, we argue, the mechanization and bureaucratization of warfare increased the relative value of shorter people permitting a decline in the average height of soldiers. Technological change over the period of these two wars affected labor demand in a way that must be recognized before using this evidence to test hypotheses about changes in population health.

Introduction

Interpreting evidence about people who have chosen to do something, while others have not, inevitably shifts the focus to circumstances influencing the decision to act. Studies pointing to a transitional deterioration in human health during the early stages of the Industrial Revolution provide a good example (Haines 2004; Komlos 1998; Steckel 1995). Much of the evidence is drawn from military enlistment, the earliest known source of mass medical examination. Interpreting this evidence encounters a question about the representativeness of people who decided to enlist. If tight labor markets (or anything else) reduced the incentive for taller men to enlist, then the enlistment would be dominated by short recruits who are unrepresentative of the population (Bodenhorn et al. 2017, 2019; Komlos and A'Hearn 2019). A convincing interpretation of such evidence requires a recognition of the selection process (Zimran 2019). In this article we argue that military evidence is also vulnerable to changes in military preference for men of different height due to evolving military strategy and/or technology, and that the selection of evidence reflects influences on labor demand as well as on labor supply.

We investigate this possibility using a military production model and a large, new data set of military recruits and policemen in the Anglo-Boer War (1899–1902) and World War I (1914–18). These two conflicts are emblematic of a longer evolution in which preindustrial technologies were at first supplanted and then replaced by machinery and mass-produced weapons. In the first half of the nineteenth century, infantrymen in all armies needed to be of a certain height to ensure that they could efficiently use muzzle-loading weapons, although the introduction of breach loaders later in the century reduced this requirement (Mironov and A'Hearn 2008: 902). Subsequent mechanization transformed military tactics and the nature of armies. Rapid-fire weapons that were especially lethal against cavalry, the rapid deployment and supply of large armies by rail, and the mass production of weapons with interchangeable parts became increasingly common. Continuous improvement of these and other technologies of war gradually reduced the role of horses and permitted the massing of exceptionally large armies during World War I.

We focus on the Anglo-Boer War and World War I because their temporal proximity allows us to examine troops drawn from the same population—men born in England between 1860 and 1890. We further control for observable characteristics such as year of birth, social class, and religion and find a significant difference between the heights. We find that participants in the Anglo-Boer War were systematically taller than their compatriots who served in World War I. What could explain this difference? Using a model in which weapons, men of different height, and horses contribute to military capacity, we posit that new technologies, and changes in military strategy entailed by those technologies, explain the difference. The Anglo-Boer War, also termed "the last gentleman's war," was the last war to use cavalry lances, a military strategy where height is a particular advantage. In contrast, the mechanization of weapons and transport during World War I meant that soldiers' heights were no longer so important, and a much broader swathe of the population was able to serve effectively. In this case, improvements to military technology help to explain the apparent decline in stature between the two wars.

Two Early-Twentieth-Century Wars

The Anglo-Boer War and World War I were two of the largest wars ever fought by Britain. The Anglo-Boer War, or Second South African War, between the Boers of the Transvaal Republic (or the South African Republic) and the Orange Free State, on the one side, and the United Kingdom with its two South African colonies—the Cape Colony and Natal—on the other, began on October 11, 1899 and lasted until May 31, 1902. Close to 450,000 British regulars and colonial forces fought in South Africa against the estimated 88,000 Boer and volunteer forces. While the Boers initially made decisive inroads, driving back the British forces to the Natal coast and deep into the Cape Colony, fresh British arrivals and poor military tactics by Boer generals meant that, within a year of the commencement of war, the British had captured the capitals of the two republics: Bloemfontein and Pretoria. The war looked like ending rapidly. Yet it would last for another two years. Boer soldiers, moving in mobile commandos, resorted to guerrilla tactics, strategically intercepting British outposts and deliveries over the vast Highveld terrain. The

British responded by instituting concentration camps for Boer women and children, sending captured Boer soldiers to prisoner-of-war camps and implementing scorched earth tactics on the abandoned farms. The war finally ended in May 1902 when the Treaty of Vereeniging was signed.

The Anglo-Boer War was the single most costly colonial war for Britain in the nineteenth century, in terms of both mortality rates and financial costs. An estimated 22,000 British and 7,000 Boer soldiers died. An additional 27,000 Boer men, women, and children died in the concentration camps, and many thousands of black South Africans, who fought on both sides of the war, also died, although these estimates are less precise. It was not only people that suffered. According to Swart, 326,073 horses, 67 percent of the total, died between the start and the end of the war. This was because "'both sides relied heavily on mounted troops" (Swart 2010: 349).

The cavalry was thus largely responsible for the defeat of the Boer forces in early 1900. Soon after capturing Pretoria, Lord Roberts, just before handing over command of the army to Lord Kitchener in December 1900, established the South African Constabulary (SAC), a volunteer force of armed and mounted police for the new British territories of the Transvaal and Orange River Colony (Fourie et al. 2017; Grundlingh 1991). The plan was to provide stability in the former republics, not only between the Boers and the British but also between the white and black farmers who still inhabited large parts of the territory. As the war continued, however, the SAC was often involved in skirmishes. In our sample of 8,873 individuals who enlisted, of whom 1,526 enlisted more than once, 20 were killed in battle.

Figure 1 shows the two British colonies, the Cape Colony and Natal, and the two Boer republics, the Orange Free State and the South African Republic. The towns where at least 100 SAC recruits were discharged indicate the concentration of the constabulary in the central and eastern Transvaal.

We use the attestation forms of the SAC for three reasons. First, large numbers of English-born recruits enrolled (57 percent of the total sample). Second, while attestation forms for more formal regiments were recorded, these often do not specify the exact height of the recruit but only whether he was above the required minimum. Third, military regiments would have had specific duties assigned to each unit. Mounted units, for example, had the specific requirement that recruits must be able to ride a horse. As far as we can determine, this was not the case for the SAC.

We also have access to the records of English-born soldiers who enlisted for service in the Anglo-Boer War in Australia, Canada, and New Zealand. We compare the English-born recruits into the Anglo-Boer War to English-born recruits enlisted in World War I. The war between the Allied Powers of France, the United Kingdom, and Russia, and the Central Powers of Germany and Austria-Hungary began on July 28, 1914 and ended November 11, 1918. An estimated 9 million combatants and 7 million civilians died in what was known as the Great War.

The reason for the large number of deaths was the size of the armies and the use of advanced mechanized technologies. Rail and steamship permitted the assembly and supply of enormous armies drawn, in the case of the Allied forces, from populations in North America, Africa, and Australasia as well as Britain and Europe. In contrast to earlier wars, the artillery were responsible for the largest number of

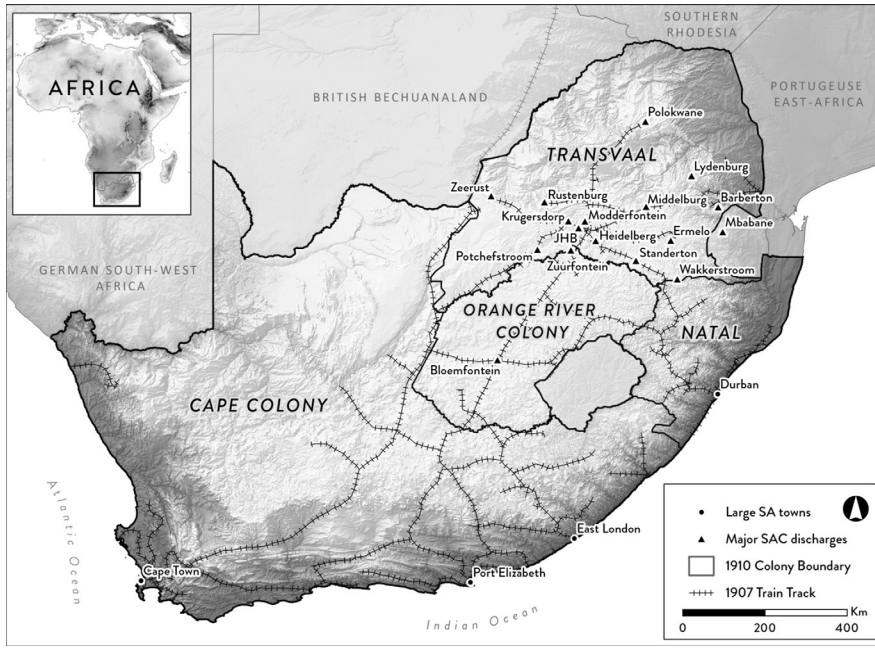

Figure 1. British colonies: Cape Colony and Natal. Boer republics: Orange Free State and South African Republic. SA = South African; SAC = South African Constabulary.

casualties (Raudzens 1990: 421). Technological developments during the late nineteenth century allowed new forms of warfare. As Castaldi et al. (2009) note, it was only during World War I that the three key mechanical constituents of the tank—bulletproof armor, internal combustion engines, and caterpillar tracks—became available. The new technologies, which included trenches, air reconnaissance, machine guns, and barbed wire, required less human muscle than the cavalry *arme blanche* that had been employed only 14 years earlier. The soldier's height became less important. The technological changes between the Anglo-Boer War and World War I are likely to have changed the selection criteria for military service.

To test this, we compare English-born soldiers in the two wars. Here we rely on the SAC described previously and data collected and used in previous studies. World War I personnel records supply information about the Australian Imperial Force (Cranfield and Inwood 2015), the Canadian Expeditionary Force (Clarke et al. 2014), the South African Expeditionary Force (Inwood and Masakure 2013), and the World War I British army (Bailey et al. 2016). The heights of the World War I forces recruited in Australia, Canada, and South Africa but born in England are compared to those of the English-born component in the SAC and in the Australian and Canadian troops sent to the Anglo-Boer War (used here for the first time). Our hypothesis is that because of the technology used in the Anglo-Boer War, height would have been important for selection into the military, whereas for World War I, selection on height would have been less important given the new military strategies.

The Horse Versus the Machine

Why did taller soldiers enlist in the Anglo-Boer War? We argue that differences in military strategy dictated by new technologies offer a novel explanation. During the early phase of the Boer War, the British still used the cavalry lance, a weapon used throughout Europe since the Middle Ages. However, the success of the lance in the Boer War was limited, with the notable exception of Elandslaagte, where a charging British force caught the retreating Boers and inflicted heavy damages (Badsey 2007: 87).

The role of the horse in combat was changing; even before the Boer war was over, the cavalry's performance had drawn substantial criticism (Phillips 2007: 38). Not only was it shifting from an instrument of combat to logistical aid but, where cavalry remained, firearms were beginning to replace the classic blade weaponry. The Boer tactics of trench warfare, their use of artillery, and, most importantly, their long-range rifles made the cavalry lance obsolete, and obliged cavalry units to became mounted infantry, dismounting to fight on foot.

Mounted units, though, remained central to the British strategy throughout the war for two reasons: the vast open geography of the Highveld together with the guerrilla tactics of the Boer soldiers during the second half of the war meant that mobility was essential. Citino (2002) notes this in examining the lessons from the war:

> The British certainly did come to understand the importance of mobility in the course of the war. The British force in South Africa changed dramatically during the war, from a predominantly infantry force, to a mix of infantry and cavalry units, to an army of mounted infantry. Mobility increased accordingly.

The need to use cavalry and to recruit soldiers fit for horse-riding was thus paramount. Although the SAC we use in the preceding empirical analysis were not necessarily recruited for the purposes of battle, they were nevertheless expected to be able to ride a horse; 93 percent of the English-born recruits in the SAC reported that they could do so in their attestation forms.[1] The Anglo-Boer War was the last in which the cavalry charge and the lancer were used *en masse*. Swart notes that the "horses in this war were among the last to engage in war the way it had been fought for more than 2000 years" (Swart 2010: 349).

In contrast, World War I was a mechanized war, especially from 1915 onward. As one French general remarked after the Battle of Verdun in 1916, "[t]hree men and a machine gun can stop a battalion of heroes" (Boot 2006: 167). "Industrial weaponry," writes Boot (ibid.: 198), made World War I "paradoxically both shorter and far more catastrophic than previous 'world wars' such as the Seven Years' War or the French Revolutionary and Napoleonic Wars." Mechanized or industrial warfare was not necessarily the strategy of choice at the start of the war; several cavalry regiments served during the first years of the war. But on the Western Front in the close quarters of trench warfare, their obsolescence was soon apparent.

[1]In comparison to only 75 percent who indicated that they could swim.

The British had realized this even before the war began. Badsey (2007: 76) notes that:

> In a wider military history context, the main impact of the Boer War was that it fostered a number of British military reforms made before the First World War of 1914–1918. Of these, one was that by 1908, alone among the major powers of Europe, the British Empire had the only cavalry entirely armed with an infantry rifle rather than the shorter carbine.

But even mounted infantry rifles would be ineffective against the industrial weapons introduced during the war, such as trench warfare with barbed wire and machine guns. Better artillery and entrenched machine guns made crossing open ground extremely dangerous. By 1916, military technology evolved further to produce the tank that was "used to crush barbed wire and eliminate machine guns" (Liaropoulos 2006: 377). Aircraft became essential in collecting information that could give armies a tactical advantage. Large numbers of horses were still used, of course, but increasingly restricted to transportation behind the lines. More importantly for our argument, the relative importance of horses and machinery was changing.

It is, or should be, evident that these new technologies required less human power than the cavalry charges of the Anglo-Boer War. This, we posit, was the reason why so few short men enlisted in the SAC. Cavalry regiments, notably lancers, were selected on unobservable factors correlated with height, such as strength. World War I soldiers, especially from 1915 onward, had less need of physical strength. In fact, the industrial weapons such as tanks, aircraft, and trench warfare may have even benefited shorter individuals.

Modeling the Impact of a Change in Technology

In modeling the shift in the preference for height we consider a military type of production function where we assume that victory in battle in the late nineteenth and early twentieth century requires soldiers, weapons, and horses. We do not for the moment consider transport to and from the battlefield.

We use a production function that highlights the impact of technological change on the substitutability and complementarity between factors of production, in particular weapons and soldiers (Krusell et al. 2000). We assume two kinds of capital: horses and weaponry. Horses in this model are used for fighting, for instance for charging at the enemy on horseback armed with a lance or other weapon suitable for use on horseback. Weapons consist of any weaponry used in the period of analysis ranging from the lances and bayonets to tanks and machine guns.

We assume two kinds of labor: tall men and average/regular height men. We allow for a growth rate in the labor stock, we also allow for growth in the efficiency of labor. This may come from technological change that is labor augmenting or simply from improvements through experience.

Together, military capital and military labor produce victories. We assume that the production function is Cobb–Douglas over horses and has a constant elasticity

of substitution over the other inputs: weapons, tall men, average men. Following Krusell et al., there are three ways of nesting weapons, tall soldiers, and average soldiers. The choice of which to use depends on our assumptions of the elasticity of substitution between average men, tall men, and weapons. We argue that if technological change is "average height-augmenting" then it shifts demand from predominantly tall men to all heights. We therefore choose a nesting that allows no impact of changes in the weapons stock on the preference for height.[2]

Let

$$V(k_{ht}, k_{wt}, l_{tt}, l_{rt}) = k_{ht}^{\alpha}\left[\mu k_{wt}^{\sigma} + (1-\mu)\left(\lambda l_{rt}^{\rho} + (1-\lambda)l_{tt}^{\rho}\right)^{\sigma/\rho}\right]^{(1-\alpha)/\sigma} \quad (1)$$

Where V is victories in time t, k_{ht} is horses in time t, k_{wt} is weapons in time t, l_{tt} is tall soldiers in time t, l_{rt} is average height soldiers in time t, and μ and λ are parameters that govern income shares. σ and ρ (σ, $\rho < 1$) govern the elasticity of substitution between tall soldiers, weapons, and regular height soldiers. The elasticity of substitution between weapons (or tall heights) and regular soldiers is $1/(1-\sigma)$ and the elasticity of substitution between weapons and tall soldiers is $1/(1-\rho)$. α is a Cobb–Douglas parameter for constant returns to scale for horses and the other inputs. If either σ or ρ are zero, the resulting production function is Cobb–Douglas.

Each type of labor input is measured in efficiency units: Each labor type is a product of the raw number of soldier hours and an efficiency index: $l_{rt} = \psi_{rt}h_{rt}$ and $l_{tt} = \psi_{tt}h_{tt}$, where h_{it} is the number of hours soldiered and ψ_{it} is the quality per hour of type i at date t. ψ_{it} in our case will denote height-specific technology.

First order conditions:

Tall soldiers:

$$\frac{dV}{dh_{tt}} = k_{ht}^{\alpha}\frac{(1-\alpha)}{\sigma}\left[\mu k_{wt}^{\sigma} + (1-\mu)\left(\lambda l_{rt}^{\rho} + (1-\lambda)l_{tt}^{\rho}\right)^{\sigma/\rho}\right]^{(1-\alpha-\sigma)/\sigma} \frac{\sigma}{\rho}(1-\mu)\left(\lambda l_{rt}^{\rho} + (1-\lambda)l_{tt}^{\rho}\right)^{\sigma-\rho/\rho}\rho(1-\lambda)l_{tt}^{\rho-1}\psi_{tt} \quad (2)$$

Regular soldiers:

$$\frac{dV}{dh_{rt}} = k_{ht}^{\alpha}\frac{(1-\alpha)}{\sigma}\left[\mu k_{wt}^{\sigma} + (1-\mu)\left(\lambda l_{rt}^{\rho} + (1-\lambda)l_{tt}^{\rho}\right)^{\sigma/\rho}\right]^{(1-\alpha-\sigma)/\sigma} \frac{\sigma}{\rho}(1-\mu)\left(\lambda l_{rt}^{\rho} + (1-\lambda)l_{tt}^{\rho}\right)^{\sigma-\rho/\rho}\rho\lambda l_{rt}^{\rho-1}\psi_{rt} \quad (3)$$

Weapons:

$$\frac{dV}{dk_{wt}} = k_{ht}^{\alpha}\frac{(1-\alpha)}{\sigma}\left[\mu k_{wt}^{\sigma} + (1-\mu)\left(\lambda l_{rt}^{\rho} + (1-\lambda)l_{tt}^{\rho}\right)^{\sigma/\rho}\right]^{(1-\alpha-\sigma)/\sigma}\mu\sigma k_{wt}^{\sigma-1} \quad (4)$$

[2]Both nesting strategies yield the same result for average height augmenting technological change. They also allow for an impact of increases in the weapons stock (whether lances or tanks) on the demand for tall and average height soldiers, which might also explain a shift in demand to average height soldiers.

Although the wage paid to soldiers is not necessarily determined by their marginal product we denote the ratio of marginal products of the two types of soldiers as the height premium to demonstrate what happens to the marginal product of height with changes in technology. The idea is that as the marginal product of average height soldiers increases relative to tall soldiers the demand for average height soldiers will increase.

We denote height premium by π and divide (2) by (3):

$$\pi_t = \frac{1-\lambda}{\lambda}\frac{l_{tt}^{\rho-1}\psi_{tt}}{l_{rt}^{\rho-1}\psi_{rt}}$$

$$\pi_t = \frac{1-\lambda}{\lambda}\left(\frac{h_{rt}}{h_{tt}}\right)^{1-\rho}\left(\frac{\psi_{tt}}{\psi_{rt}}\right)^{\rho}$$

Log-linearizing and removing constants:

$$ln\pi_t = (1-\rho)ln\left(\frac{h_{rt}}{h_{tt}}\right) + \rho ln\left(\frac{\psi_{tt}}{\psi_{rt}}\right)$$

In this specification, changes in the height premium and hence the marginal products take place through the hours soldiered and changes to the efficiency of soldiering. In particular, the height premium decreases if the efficiency of regular height soldiers increases and $\rho > 0$. How might regular height soldiers become more efficient? The weapons technology could develop in such a way that it augments the productivity of all heights not just the tallest and strongest. For example, advances in artillery might reduce the requirements for strength or advances in the use of chemical weapons need not require strength. We argue that these and other weaponry and tactical changes described previously would indeed have caused a substitution away from tall soldiers. An increase in the overall stock of weapons would not affect the height premium in this model, however the demand for both types of labor relative to weapons would increase.

World War I was, of course, much larger than the South Africa war. The sheer size of World War I led to the enlistment of shorter soldiers to meet recruitment targets (Shlomowitz 2007). And yet, the scale of the war also reflects technological change because short soldiers would have been less useful in the absence of improvements to the productivity of the not-so-tall. More broadly, moving beyond the model, technological change in transportation and communications permitted the assembly, organization, and supply of increasingly large armies—just as it did for business enterprise (Chandler 1962, 1977). And within the complex administration of a large army, tasks for which stature did not enhance productivity occupied increasing numbers of personnel. Thus, within the model and more broadly, we can see that the scale of World War I was partly dependent on technological change and not simply a product of the political alliances that also contributed to the scale of combat.

Evidence of Height Differential

We compare seven groups that fought in either the Anglo-Boer War or World War I. We restrict our attention to men who were born in England between 1860 and

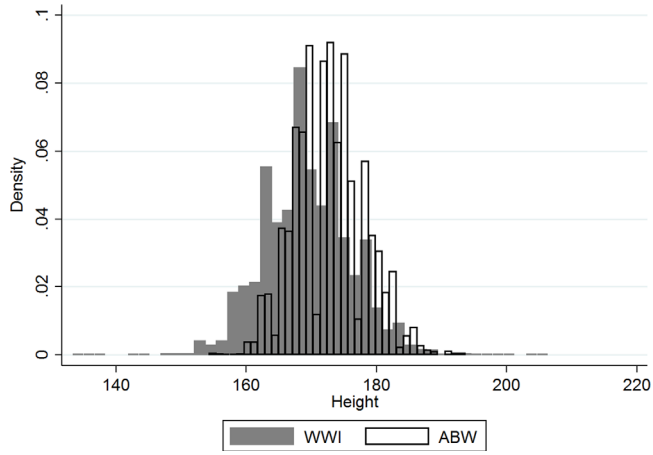

Figure 2. Histogram of heights in two wars.

1890 to minimize the risk that differences in birthplace or cohort might influence our results. We can structure the investigation in this way because large numbers of men from this cohort migrated to Australia, South Africa, and Canada. Anglo-Boer War and World War I enlistment records are available for armies raised in Australia, Canada, and South Africa. We use British Army records for World War I only because its surviving Anglo-Boer records do not include height. These data allow us to ask, in effect, what kinds of men among those born in England 1860–90 were selected for the two conflicts, independently in the four jurisdictions.

Figure 2 superimposes histograms of height distributions from the two enlistments (all forces combined). The lumpiness arises from a degree of heaping in height reporting, which was given in inches but here is converted to centimeters. Both distributions are near-normal although the Anglo-Boer has a greater shortfall at low heights and, of course, is shifted to the right. Both wars enlisted men with a wide distribution of heights, although the Anglo-Boer War appears to have made little use of noticeably short men.

Further descriptive detail is presented in table 1 and figure 3. A general height difference between the two wars is clear. English-born recruits who enlisted in the Anglo-Boer War, regardless of enlistment location, on average were taller than soldiers in all the World War I armies. The smallest mean height in the 1899–1902 conflict (Australian forces) was larger than the largest mean height in World War I (South African forces). English-born Canadian soldiers recruited in the Anglo-Boer War were on average more than 3 centimeters taller than the English-born recruited more than a decade later in Canada. Presentation of 95 percent confidence intervals in figure 3 reinforces the point. This difference in means supports our hypothesis of different selections in the two wars even if we restrict examination to the same cohort and birthplace. Larger standard deviations of height in World War I are also consistent with an ability to make greater use of short men.

Table 1. Descriptive statistics of World War I (WWI) and Anglo-Boer War (ABW) soldiers born in England, 1860–85

	Origin	Obs.	Height Mean	Height Median	Height Std. Dev.	Birth Median	Age Median	Hisco Median
WWI	England	3,594	168.0	167.6	6.42	1883	32	75
WWI	Australia	4,734	169.8	169.9	6.33	1889	26	73
WWI	Canada	15,424	169.5	169.5	6.60	1888	27	71
WWI	South Africa	1,356	171.1	170.5	6.29	1882	34	58
ABW	South Africa	4,387	172.9	172.7	5.25	1878	23	62
ABW	Australia	375	171.6	171.5	5.73	1877	25	63
ABW	Canada	1,063	172.6	172.1	5.41	1876	25	62
Total		30,933	170.1	170.2	6.46	1884	27	62

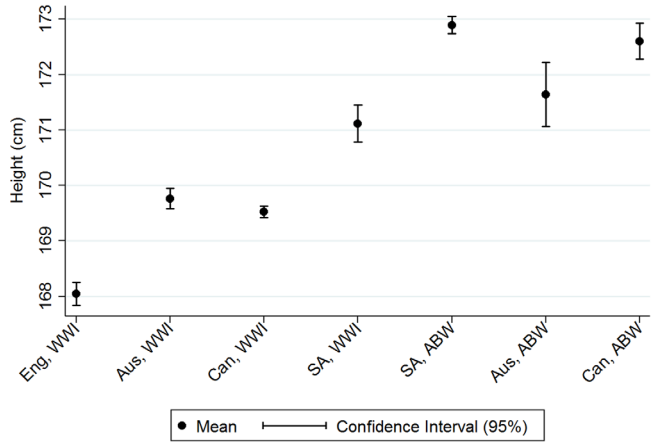

Figure 3. Mean height with 95 percent confidence intervals for the seven enlistments.

Table 1 also gives the median year of birth, the average age, and the modal occupation type. There are few notable differences, but it is useful to note the modal occupation for those recruited to the Anglo-Boer War is farmer, while for World War I it is unskilled laborer. This and other compositional differences suggest the importance of a multivariate adjustment for the effect of observable characteristics. We do not and by definition cannot know of any unobservable differences across enlistments, but the identification of occupation, religion, and birth year at least allows us to test if the difference between wars survives adjustment for the marginal effect of several important personal characteristics.

We use a simple multivariate analysis to explore further reasons for the difference between wars. To do this, we estimate the following model on the pooled sample:

$$Height = \beta_0 + \beta_1 War + \beta_2 Country + \beta_3 BirthYear + \beta_4 Hisco + \beta_5 Religion + \varepsilon$$

Our variable of interest is war, which equals one for the Anglo-Boer War and zero for World War I. There is no reason to suspect, *a priori*, that controlling for the observable characteristics of individuals—country of enlistment, birth year, occupation, and religion—would undermine statistical significance on the coefficient for the war dummy. However, if such a significant coefficient is found, we hypothesize, it could suggest a different recruitment policy that might be related to technology.

In table 2 we report six different ways of identifying factors that are associated with individual stature and potentially may explain the difference between wars. We employ ordinary least squares in the first four specifications and a truncated regression approach in the last two (A'Hearn 2004; Komlos 2004). None of the econometric experiments reported in table 2 modify the impression given by the descriptive observations in the preceding text. A large and statistically significant difference between those fighting in the two wars survives the multivariate control for observable characteristics. Regardless of specification and estimation technique, the difference remains larger than 2 centimeters except in Specification 6 (1.7cm); in some specifications it rises to 4 centimeters.

Why do we observe such a height difference between people born in the same country (England) during roughly the same period but recruited to two different wars? Observable characteristics do not seem to explain the difference: We control for birth year, place of enlistment, occupation, and religious differences that should capture any selection on observable characteristics. We know, for example, that following British defeats during the initial stages of the Anglo-Boer War, many upper-class Englishmen felt it their duty to enlist to protect the British Empire. Such patriotic fervor would have biased the sample in favor of taller individuals and that is indeed what happened. In 1900, English-born recruits to the SAC are on average 174 centimeters tall whereas in 1901 their average was 172.8 centimeters. Yet because we include occupation and religion, our control variables should remove this influence.

A more serious possible bias is the selection of height. Toward the end of World War I, the numbers of qualifying men who could still enlist dwindled. The authorities were thus forced to lower the minimum height requirement to recruit more soldiers. We would expect that the relaxation of this requirement would push the average height of recruits down, and indeed, between 1914 and 1917 the average height of soldiers fell from 170.3 centimeters in 1914 to 168.7 centimeters in 1917 (Appendix figure A1, see online supplementary materials).

We mitigate these concerns in several ways. First, in the latter specifications we include controls for year of birth and year of enlistment. These should control for any year-specific changes (such as patriotic fervor or a decline in the availability of recruits). We also exclude the outlier years (unreported), with no changes to our results. In the supplementary appendix we provide additional robustness checks to show that our main result holds regardless of the point of truncation, the

Table 2. Regression results: association of individual characteristics with height

	Spec (1)	Spec (2)	Spec (3)	Spec (4)	Spec (5)	Spec (6)
ABW	3.588***	2.517***	2.131***	4.015***	4.006***	1.729**
	(27.62)	(15.81)	(12.80)	(8.97)	(7.95)	(2.76)
Australia		1.720***	1.652***	1.922***	1.942***	1.280***
		(11.58)	(9.13)	(10.58)	(8.40)	(3.80)
Canada		1.776***	1.658***	1.879***	1.971***	1.695***
		(14.51)	(10.29)	(11.60)	(9.43)	(5.50)
South Africa		2.852***	2.753***	3.429***	3.501***	2.748***
		(15.96)	(13.22)	(15.69)	(13.02)	(7.31)
Hisco 0			1.075***	1.023***	1.069***	0.573
			(4.88)	(4.66)	(4.29)	(1.88)
Hisco 1			0.655**	0.685**	0.458	−0.262
			(2.61)	(2.74)	(1.59)	(−0.71)
Hisco 2			0.774*	0.903**	0.797*	0.154
			(2.31)	(2.70)	(2.06)	(0.31)
Hisco 3			0.421*	0.371*	0.344	−0.159
			(2.53)	(2.24)	(1.78)	(−0.65)
Hisco 4			0.756***	0.727***	0.698**	0.043
			(3.49)	(3.37)	(2.81)	(0.14)
Hisco 5			−0.288	−0.304	−0.342	−0.590*
			(−1.64)	(−1.73)	(−1.66)	(−2.22)
Hisco 7			−1.409***	−1.399***	−1.540***	−1.432***

(*Continued*)

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Table 2. (*Continued*)

	Spec (1)	Spec (2)	Spec (3)	Spec (4)	Spec (5)	Spec (6)
			(−8.20)	(−8.17)	(−7.41)	(−5.07)
Hisco 8			−1.109***	−1.127***	−1.302***	−1.636***
			(−7.01)	(−7.15)	(−6.88)	(−6.41)
Hisco 9			−1.240***	−1.288***	−1.522***	−1.690***
			(−9.47)	(−9.86)	(−9.75)	(−8.10)
Other Protestant			−0.618***	−0.522***	−0.637***	−0.668***
			(−5.43)	(−4.59)	(−4.62)	(−3.55)
Roman Catholic			−0.887***	−0.882***	−1.132***	−0.610
			(−4.64)	(−4.63)	(−4.80)	(−1.86)
Jewish			−4.955***	−4.831***	−5.027***	−4.696**
			(−7.53)	(−7.37)	(−5.14)	(−2.87)
Nonreligious			0.678	0.628	0.631	0.929
			(1.17)	(1.09)	(0.94)	(1.07)
Yr birth	YES	YES	YES	YES	YES	YES
Yr enlist	NO	NO	NO	YES	YES	YES
Constant	169.581***	168.151***	168.886***	167.944***	168.040***	171.069***
	(482.09)	(464.74)	(417.77)	(387.15)	(325.18)	(251.67)
Sigma constant					6.404***	5.749***
					(148.92)	(85.13)
R-squared	0.041	0.053	0.066	0.076		
N	24761	24761	22505	22505	21562	14074

Notes: World War I, English recruits, farmers (Hisco 6), and Church of England are the control groups. ABW stands for Anglo-Boer War. Models 1–4 employ an ordinary least squares estimation. Models 5 and 6 are estimated using a truncated regression approach.
* significant at the 10 percent level; ** significant at the 5 percent level; *** significant at the 1 percent level.

minimum age of recruits or the year of enlistment in World War I (Appendix figures A1, A2, A3, and A4, see online supplementary materials).

Conclusion

It seems clear that enlistments in the Anglo-Boer War and World War I represent different selections of men born in England between 1860 and 1885. We have argued on conceptual grounds that changes in military technology might plausibly alter the demand for different kinds of soldiers in a way that reduced average stature. And we demonstrate that military technology changed in exactly this way from the Anglo-Boer War, which was largely a conflict between horse-mounted units, to the increasingly mechanized armies of World War I. Thus, the evolution of military stature is consistent with our simple models of labor and technology. This observation is based on an examination of a single cohort of English born who enlisted in four distinct locations and is robust to statistical controls for a range of potentially intervening influences, decisions about truncation point, and the inclusion of outliers.

This is not to deny other explanations. We consider three possibilities. One influence of potential importance is the business cycle (Bodenhorn et al. 2017, 2019). Differences in the state of the business cycle between 1899 and 1914 might, in principle, account for some of the decline in military height if labor markets were looser in 1899 (forcing more of the taller men into military service) than in 1914. Although difficult to evaluate fully, the circumstances of our four economies make a business cycle effect along these lines unlikely.

Canada clearly does not conform to this scenario because labor demand was increasing rapidly during the 1899–1902 enlistment and in marked decline during 1913 and 1914 (Safarian 1970, 26; Urquhart 1993). The South African economy's contraction 1913–16 also began before the outbreak of war (Boshoff and Fourie 2020: Appendix 1). The picture for Australia is less clear; most of that literature considers long term trends rather than the business cycle (Haig 2001; McLean and Pincus 1983). At a minimum, however, employment in commodity export industries must have declined during 1914 and 1915, as also in Canada and South Africa, because of trade decline as the conflict widened. For Britain, nominal wages grew robustly in 1899 and 1900; Crafts and Mills (1994) do not identify a break in real wage growth until 1903. In contrast, at the beginning of World War I British unemployment likely would have increased markedly if not for military enlistment because of the curtailing of large-scale emigration.[3] More broadly, differences in business cycle trajectory in our four recruiting locations make it unlikely that collectively they contributed much, if at all to the observed stature decline.

A second potential complication is the adverse health and nutrition consequences of early industrialization. If population health was deteriorating, that might account for shorter soldiers in World War I. We minimize this problem by

[3]Indeed, if business cycle effects dominate and military enlistment followed prewar patterns, a slowing of the global economy during World War I should have led to *increasing* rather than decreasing heights as more tall men were driven into the armed forces.

comparing soldiers in the two wars born in the same cohort. Admittedly, World War I soldiers were born disproportionately later in the cohort than the Anglo-Boer War soldiers. And yet, all our models specify year of birth as an explanatory variable. This effectively removes from consideration any downward pressure on stature due to deteriorating health late in the century.

Finally, the scale of combat mattered. The size and duration of World War I, and high rates of mortality, forced all the armies to relax recruiting standards as the War advanced. World War I was larger and longer, in part, because Germany and its allies were a more formidable opponent than the two Boer republics. And yet, technological change also contributed to the scale of conflict. As our model suggests, technological change broadened the pool of acceptable recruits through an improvement in the productivity of short men. More broadly, advances in transportation and communications technology permitted the assembly, coordination, and supply of very large armies. Thus, the scale and technology effects reinforced each other. Together, they imply that a comparison of the two enlistments should *not* be used as evidence of declining stature in the wider population from which soldiers were selected. Rather, we are seeing the effects of a selection arising from labor demand that has not previously be recognized in the selection bias literature.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/ssh.2020.16

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