Airborne Diseases: Tuberculosis in the Union Army

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Abstract

Tuberculosis represents by far the greatest decline of a single condition in the escape from high mortality of Northwest Europe and North America. Although the role of tuberculosis (TB) for the mortality decline remains undisputed, very little agreement exists today on the causes of the decline of TB morbidity and mortality. Since no effective treatment was available prior to the 1940s, only host and environmental factors seem to have a role in its decline. According to the Union Army evidence discussed in the paper, height reduces the probability of diagnosis, discharge and death from tuberculosis. Taking height as a measure of nutritional status, our study corroborates the importance of adequate nutrition for the secular mortality decline. Also, stress factors contribute to the activation or acquisition of tuberculosis while in the Union Army. Recruits who experienced gunshot wounds and participated in more battles were more likely to suffer from tuberculosis.

[PRELIMINARY - COMMENTS WELCOME]

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1 Introduction

This paper studies mortality and morbidity from tuberculosis in a sample of Union Army recruits during the Civil War in order to shed some light upon the determinants of adult morbidity and mortality in historical populations. The importance of tuberculosis for the high levels of mortality before 1750 has been consistently corroborated. In fact, the secular decline in mortality of Northwest Europe and North America depended greatly on reductions in the morbidity and mortality of tuberculosis as McKeown [26] and many others have shown. For example, according to McKeown ([26], Table 3.1), airborne infectious diseases contributed to 40 percent of the decline in death rates in England and Wales between 1851 and 1971, with tuberculosis representing 17.5 percent of the overall decline. Also, according to Caselli [4], from 1871 to 1951 England and Wales gained 27 years of life expectancy at birth due to the mortality decline. Of the 27 years gained, tuberculosis represents about a 40 percent contribution or a 12 year gain. In terms of the contribution to overall death rates or life expectancy, tuberculosis represents by far, the greatest decline of a single condition in the escape from high mortality.

Although the role of tuberculosis for the mortality decline remains undisputed, very little agreement exists today on the causes of the decline of TB morbidity and mortality. Mercer [27] has suggested that TB, as a sequel of smallpox infections, declined due to the vaccination against smallpox initiated in the eighteenth century. Yet, smallpox has been eradicated in the world for at least a decade but tuberculosis still contributes significantly to the current mortality of less developed countries. Each year 54 million people in the world acquire the tubercle bacillus (*Mycobacterium tuberculosis*), 6.8 million develop a clinical disease, and 2.4 million people die of tuberculosis. Tuberculosis causes 5 percent of all deaths worldwide, and 9.6 percent of adult deaths in the 15-59 age group, NIAID [29].[1] Alternative explanations based on exogenous changes in the virulence of the infective organism, for example Woods and Shelton [40], also fail to account for the persistent infectivity of tuberculosis in less developed countries as well as the recent recrudescence of the disease in developed countries after 1980.

In less developed countries today, as well as in historical populations, most of the death rates

[1] In addition, the Global Burden of Disease Study of Murray and Lopez [28] determined that tuberculosis represents the seventh leading cause of Disability Adjusted Life Years (DALYs) in the world, and unlike most infectious diseases, will still be among the top ten causes of DALYs in 2020.

from TB depend on high morbidity levels since its case fatality rate is very high. Between 40 to 50 percent of untreated cases die of the disease, NIAID [29]. Also, as Drolet [11] shows, case fatality ratios for tuberculosis, for almost all ages, varied very little in American cities before 1938 even though the incidence of the disease declined 50 percent. As Drolet [11] and Puranen [30] show respectively, England and Wales, and Sweden shared a similar decline in prevalence and a constant case fatality ratio.

Tuberculosis is an endemic infection that activates according to socioeconomic and environmental determinants. In our sample, recruits may have been free from active tuberculosis when they enter into the Union Army, even though they would have probably test positive on a tuberculin test.[2] For that reason, the activation of the disease during the Civil War serves to illustrate the contribution of different *stress* and environmental factors to TB morbidity and mortality. The paper adds several elements to the discussion of adult mortality from infectious diseases. Since some of the causal factors of the disease can be found in the Union Army sample collected by Fogel [17], we link individual information and socioeconomic characteristics of the population at risk to study the determinants of tuberculosis.

The paper proceeds as follows: Section 2 studies some epidemiological aspects of tuberculosis. Section 3 discusses the evolution of tuberculosis and its contribution to the escape from high mortality in Northwest Europe. Section 4 analyzes the US experience prior to the Civil War based on military information. This comparison is done to ensure reliability in the Union Army sources. Section 5 describes the Union Army data and the main results of the paper. We conduct the analysis in terms of probabilities of diagnose, discharge and deaths from tuberculosis, as well as the number of days free from tuberculosis. Section 6 concludes.

[2] Positive tuberculin testing is not uncommon. According to Trump [38], more than 12 million US navy recruits received a tuberculin skin test from 1958 through 1969; 5.2 percent presented a positive reaction. For 1990, the prevalence rate of positive reactions has been reduced to 2.5, although Blacks, Hispanics and Asians exhibit greater rates than Whites. Foreign born recruits also presented higher prevalence rates. Sagan ([33], 33) presents an age pattern of positive tuberculin testing in 1940 for the US population; at ages 0-1, the percentage infected is less than one but increases steadily until ages 40-45. This high prevalence is consistent with reactivations of endogenous latent infections for White population, Hawker et al. ([20], 1031).

2 Some Epidemiological Aspects

Tuberculosis is a chronic infectious disease most commonly associated with the lungs. TB can affect almost any tissue or organ, but pulmonary tuberculosis represents between 80 to 90 percent of all known cases. The disease responds to multifactorial causation due to interactions between the host and the host environment and it reaches humans almost exclusively through aerial transmissions. Infected individuals develop a latent or persistent infection that can remain viable throughout their host life until resistance fails, whereupon the disease activates. Comstock and Cauthen [8], and Johnson [21] provide summaries of TB's etiology and epidemiology.

Progression rates to active TB correlate with socioeconomic measures according to the evidence from Felton and Ford [14] and Hawker et al. [20].[3] For instance, once the individual becomes infected or possesses a latent form of the infection, the activation of the disease depends on two general aspects: host and environmental factors. Host factors include age and gender. Infancy, puberty and old ages are periods of low resistance and high susceptibility to tuberculosis as evidenced by Comstock et al. [7], Dutt and Stead [13], and Meyer [**?**]. In addition, nutrition plays a key role in TB etiology in epidemiological and laboratory evidence, see for example Chandra [5] and Raloff [31]. People with good diets reduce susceptibility to the disease compared to individuals who suffer from malnutrition or those with a poor diet. Protein deficiency is particularly dangerous, especially a lack of animal proteins.[4] In fact, as Comstock and Cauthen [8] note, a benefit of being overweight is the association with protection against tuberculosis. Puranen [30] presents a summary of the relation between nutrition and tuberculosis.

Environmental factors also trigger the activation or acquisition of tuberculosis. An increase in the number of people per room or alternative measures of crowding increase the chances of infection by prolonged exposure.[5] Occupation and working conditions also tend to affect the outcome of the disease; workers in "dusty trades" inhale particulate matter that inflames the lungs and increases their risk of developing the disease. The physical exertion and stress of

[3] The resurgence of tuberculosis in Britain after 1980 also correlates with poverty rates and socioeconomic factors. Additional examples include Bhatti, et al. [2], Mangtani et al. [25], Spence et al. [34], and Tocque et al. [36].

[4] As the Medical History of the Civil War ([39], Vol. 6, 828) indicates, the method of treatment for tuberculosis involved the administration of cod-liver oil, tonics and stimulants, with extra or generous diet and warm clothing.

[5] For example, US naval ships present closed environments with controlled ventilation ideal for the transmission of TB infection. Trump [37] presents an example.

exhausting activities also magnifies the risk of developing tuberculosis, as does smoking, Johnson [21].

3 The Mortality Decline from Tuberculosis

In pre-industrial economies mortality from tuberculosis varied considerably due to the urban composition of the population. Throughout the mortality decline, cities exhibited a substantial penalty on TB mortality and morbidity. Because of overcrowding, poor living conditions, and increased exposure, tuberculosis was far more common in urban concentrations during the late eighteenth century. According to Landers [22], in the London bills of mortality, the contribution of tuberculosis to overall mortality almost doubles from 12.9 percent during 1700-1725 to 24.5 percent during 1775-1800. Stockholm presented a similar situation; during 1750-1830, mortality rates from pulmonary tuberculosis exceeded 8 per thousand (or a nearly 1 percent chance per year of dying of tuberculosis), the highest known rate for a major city at that time, with a contribution of tuberculosis of more than 20 percent to total deaths, Puranen ([30], 101). Paris presented an increase in the death rate from TB from 3.4 during 1816-1819 to 5 deaths per thousand by 1865-1872, reaching a peak of 7 deaths per thousand at the time of the Franco-Prussian war and the subsequent siege of the city, Barnes ([1], Figure 1).

The internal migration and the concentration of urban populations affected overall mortality from tuberculosis in Northwest Europe. For example, in England the death rate from tuberculosis seems to have peaked around 1770 at a level of 7 per thousand, Cohen [6]. Small towns in Finland also exhibit a sustained increase in death rates from tuberculosis after 1750. TB mortality started from a death rate of 3 per thousand, with a similar peak around 1860 at about 5 deaths per thousand. Sweden's peak was reached between 1870 and 1875 at lower levels, Puranen [30]. According to Barnes [1], tuberculosis increased gradually in France reaching a peak in the late 1880s and early 1890s.

In all the previous cases, after the death rate from TB reached a peak, it started a secular decline. Aside from a few outbreaks experienced during both World Wars, Dubos and Dubos [12], mortality from TB declined gradually through most of the twentieth century in Europe prior

to any medical innovation in its treatment.[6]

4 Tuberculosis in Nineteenth Century America

In the nineteenth century US, mortality varied according to residence. Mortality rates were much higher in cities than in small towns or rural areas because high concentrations of people in small areas accelerated the spread of communicable diseases. Tuberculosis represents a particular case by the urban nature of the disease. By 1850, tuberculosis mortality rates in the principal US cities were higher than 5 deaths per thousand, Grigg [19], but the average mortality rate due to TB in the country was of only 1.71 (in males). The difference arises because at that time, only 16 percent of the total US population were residing in urban areas.

The mortality statistics of the seventh census of the United States in 1850 provide an estimate of TB death rates previous to the Civil War. Table 1 displays age specific death rates and the total contribution of TB to overall mortality by age. As the table indicates, the median age of death from tuberculosis was mid-life since the disease was particularly lethal for the group between 20 and 50 years of age; almost one out of every five adults who died in that age group died from TB. Deaths from tuberculosis contributed little to infant and elderly mortality, although both groups experienced relatively high death rates.

Table 1. US mortality, 1850.

	Under 1	1-4	5-9	10-19	20-50	50-80	Over 80	Total
Death rate (per 1000)	108.18	30.32	8.41	6.07	12.19	30.30	148.30	17.23
TB death rate	2.50	0.77	0.20	0.50	2.10	4.29	6.69	1.54
Contribution of TB	2.31	2.55	2.40	8.31	17.24	14.18	4.51	8.96

To study mortality differentials, Ferrie [15] links the mortality and the population schedules of the 1850 and 1860 in the Federal Population Censuses. In the case of TB, Ferrie [15] finds

[6] Dubos and Dubos [12] present evidence of increasing mortality from tuberculosis during the first and second World Wars especially for the Netherlands, Denmark and Belgium. Between 1913 and 1917 the respiratory tuberculosis death rates increased approximately 17 percent (35 percent for the period 1913-1918 which includes the influenza pandemic) in England and Wales, Bryder ([3], 109). Bryder ([3], Chapter 4) also documents the adverse effects of inadequate nutrition during the war and recessions in Great Britain, Germany and Denmark.

that farmers and laborers experienced lower mortality. For old cohorts, Ferrie [15] also finds an age pattern of mortality.

For the purpose of our study we consider nineteenth century information from military sources. The Surgeon General's Office compiled reports on the hygiene statistics of the United States Army forts from 1829-1874. Even though the principal diseases against which the Army surgeons used remedies were those classified as fevers (especially malaria), respiratory diseases and TB were also reported. With the information available in the Forry [18] and Coolidge [9] reports of the US Army forts between 1839 and 1854, we construct a prevalence measure for TB. Figure 1 presents the regional prevalence of tuberculosis in US forts.[7] Prevalence rates were high compared to current rates, at values near 30 per thousand.

On average, the prevalence of tuberculosis in North forts between 1839 and 1854 is around 11 per thousand. This number is particularly useful since it will provide a comparison with the morbidity measures obtained in the Union Army. In fact, as we next show, in the Union Army, the discharge rate due to tuberculosis also equals 11.

Regional and seasonal analysis (not reported in the text) suggests that the fourth and second quarters present a higher prevalence in the South and Middle regions of the US, while the second and third are the most important in the North. During any season, the disease affected more people in the South.[8] Since TB exhibits relatively high case fatality rates[9], a death rate of 6 or 7 per thousand in the Army forts is not unfeasible given the prevalence numbers obtained above.

Mortality from tuberculosis in the US began its decline in the mid-nineteenth century, Sagan ([33], Figure 2.1). In Massachusetts, mortality from pulmonary tuberculosis declined from 4 deaths per thousand in 1857 to less than one at around 1920, while in the US tuberculosis death rates fell by 77 percent from 1900 to 1935, Sagan ([33], 28). During the secular decline no effective treatment against TB was available although several therapies were attempted against

[7] The Northern US includes the portion which lies north of the fortieth degree of latitude, and east of the Rocky mountains; the Middle includes the portion lying between the thirty-fifth degree of latitude and fortieth parallel of latitude. The South refers to the division between the thirtieth and thirty-fifth degrees of latitude. Linares [24] discusses the methodology and general patterns of disease. More information is available at *www.cpe.uchicago.edu*

[8] The mortality rate from tuberculosis was high among slaves acording to the Mississippi mortality tables, Stampp [35].

[9] Case-fatality rates for sputum-positive cases prior to the introduction of tuberculosis chemotherapy were around 50 percent. Murray and Lopez [28] present a review in their GBD project. The rates are consistent with the evidence of Drolet [11].

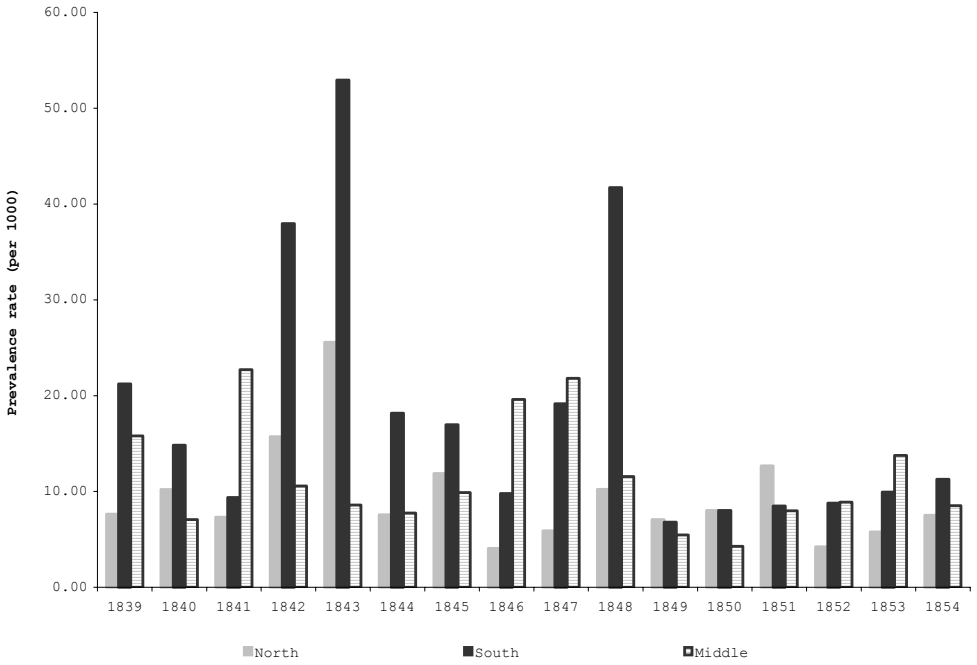

Figure 1: Regional prevalence of tuberculosis, 1839-1854.

the disease, Bryder [3].

5 Union Army Data and Methods

The data employed in the paper is drawn from the Military Service Records of the Early Indicators Project described in Fogel [17]. The primary sample consists of 35,747 white males mustered into the Union Army during the Civil War. Available information of military, socioeconomic, and medical variables for these men is derived from several sources throughout their lifetimes.[10] The "Military, Pension, and Medical Records" which is the largest dataset in the EI project, is derived from military-related documents housed in the National Archives in Washington, D.C.

The analysis of information during the war has shed some light into the evolution of mid-life

[10] For more information visit *www.cpe.uchicago.edu.*

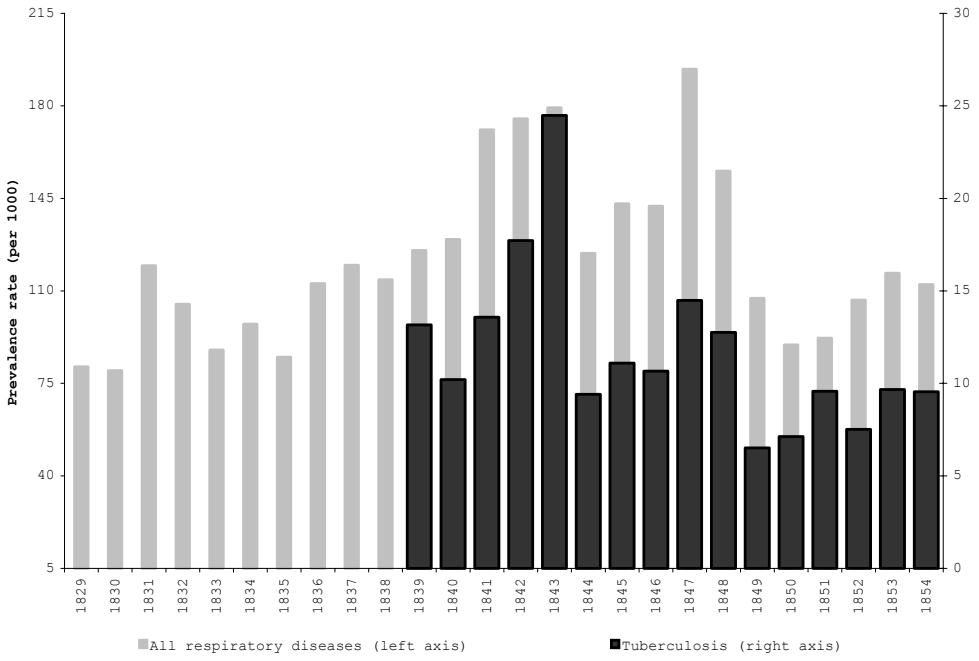

Figure 2: Prevalence of tuberculosis and respiratory diseases in US forts.

and old age mortality in the US. For example, according to Costa [10], infectious respiratory diseases during the Army were particularly harmful for old age mortality. Veterans aged 50 to 64 with respiratory infections during the war, including tuberculosis, experienced higher disease mortality at later ages. Also, Lee [23] identifies important socioeconomic factors on the disease and mortality experience of Union Army recruits. In both cases, as well as in most examples, aggregate conditions such as infectious vs. non-infectious diseases or diseases sensitive to nutritional vs. diseases not sensitive to nutrition are considered without a detailed analysis of specific conditions. The analysis of tuberculosis constitutes, then, an initial attempt to isolate specific disease mortality in historical populations.

There are three main sets of variables in which we can identify if tuberculosis was ever diagnosed and reported for any recruit from the beginning of the war onwards. They are:

(a) If the recruit was ever hospitalized due to tuberculosis,

(b) if the recruit was ever discharged from duty due to tuberculosis, and

(c) if the cause of death was associated with tuberculosis.

Table 2 describes the available information for these three cases. The total number of observations has been reduced from 35,747 to 21,052 due to the exclusion of outliers or recruits with inconsistent information. In our adjusted sample, 2 percent of the recruits were diagnosed with tuberculosis while 1 percent were discharged due to the disease.

Deaths from tuberculosis were uncommon during the war since the regiments were relieved of their recruits by discharge and not by death.

Table 2. Tuberculosis in the Union Army.

	Frequency	Rate per 1000
Diagnosis of TB	426	19.82
Discharge from TB	227	10.54
Deaths from TB (before 1865)	39	1.81
Deaths from TB (before 1875)	219	10.26
Deaths from TB (before 1895)	538	25.11
Deaths from TB (all years)	696	32.45

The number of deaths from tuberculosis largely understates the impact of the condition on the Union Army. *Post-mortem* examinations, discussed in the Medical History of the Civil War ([39], Vol. 6), frequently indicate the condition on patients who died from pneumonia, diarrhea, dysentery, and malaria. Still, mortality from TB increased substantially as the recruits aged causing 2 percent of the deaths by 1895 and 3 percent of all deaths in the sample.

Table 3. TB prevalence and regiment size.

	Prevalence	Number of			
Regiment size	(per 1000)	regiments	cases	discharges	deaths
<50	17.32	45	14	9	1
50-99	21.19	49	77	32	8
100-149	15.82	36	73	41	12
150-199	23.58	15	60	25	2
200-249	22.06	9	44	29	0
250-299	17.88	7	34	5	3
300-349	16.38	4	21	15	4
350-399	30.22	5	57	43	4
≥400	16.34	6	47	28	5
χ^2 for Kruskal-Wallis			20.21^{***}	44.39^{***}	8.52

***p<0.01, **p<0.05, and *p<0.1

As Table 3 indicates, tuberculosis spread uniformly over the different regiments. There is no clear association between the size of the regiment and the prevalence of the disease; for instance, the prevalence of tuberculosis in the smallest regiments (regiments with less than 50 recruits) exceeds the prevalence in the regiments with more that 400 soldiers, although the Kruskal-Wallis test rejects an equal distribution of diagnosis and discharges across regiments.

Table 4. Sample statistics of Union Army recruits.

Variable	Mean	Std. Dev.	Min	Max
Days in the Army	611.22	373.49	2	1863
Days mustered in	591.65	366.65	1	1853
Age of				
Enlistment	25.81	7.84	12.00	88.00
Discharge from TB	27.26	8.85	16.59	62.67
Diagnose from TB	26.49	7.87	16.39	51.29
Death from TB	29.85	7.54	18.63	50.29
Death from any cause	67.37	16.19	16.67	109.63
Days before				
Discharge from TB	376.66	266.62	56	1304
Diagnose of TB	346.20	271.65	3	1792
Death from TB	656.63	406.60	118	1431

Tables 4 and 5 present additional sample statistics. On average a soldier remained active

for 611 days in the Army, but only 376 days were required for a discharge due to tuberculosis. As we mentioned before, regiments were relieved of tuberculosis by discharge. The diagnosis of tuberculosis took on average 346 days. The soldiers dying from TB while in the Army stayed in service an average of 656.63 days, 6 weeks more than the average recruit did, although the standard deviation exceeds 400 days. In contrast to diagnose or discharge, most of the deaths took place late in the service although the small number of cases prevents a detailed characterization. On average, discharge and diagnose took place after a year in service however, the cases reported extended well over three and four years. For that high dispersion in the timing of diagnose, discharge, and death we consider a logit analysis to assess the effects of wartime stress and additional factors on TB morbidity and mortality.

The analysis of diagnose probabilities is based on a logistic regression. The odd ratios are presented in Table 5 for both, the probability of being diagnosed and discharged. The regressions include height as a proxy for nutritional status at early ages as well as war-related variables like the number of battles, the presence of gunshot wounds, and POW status. Occupation at enlistment is also included, although a specific classification of laborers and artisans exposed to fumes and dust was not accounted for. In the sample, recruits fought on average 0.6 battles, and 8 percent of them were POW. Height was on average 1.71 meters. The main occupation was farming, 53 percent of the sample, and according to Table 5, more than 85 percent of the population was enlisted from towns with populations of less than 2,500 inhabitants. Finally, cohort effects described by the year of birth are included. As usual, there is a very tight connection between cohort and age effects, so a separate characterization is not attempted here.

A set of co-morbidities includes diarrhea and fevers among other diseases (malaria, measles, and typhoid). Both conditions were highly prevalent during service, more than 20 to 25 percent of the recruits respectively were ever hospitalized for those afflictions. Pneumonia, bronchitis and pleuritis are often related to TB but it is difficult to determine the timecourse of the diseases to separate causal effects from diagnosis limitations. Dummy variables for the size of the city at enlistment in 1860 were included to measure the extent of crowding and exposure to the disease before entering the Army; as we mentioned before TB can remain in latent states for prolonged periods of time.

Table 5. Probability of TB diagnosis and discharge.

		Pr(Diagnose=1)	Pr(Discharge=1)
	Mean	Odds ratio	Odds ratio
Height (in m)	1.718	0.082***	0.009***
Number of battles	0.604	1.066	1.380***
Dummy=1 if in war			
Gunshot wounded	0.154	1.493**	1.530
POW	0.081	1.182	1.255
Dummy=1 if occupation at enlistment			
Farmer	0.531	1.136	0.809
Professional	0.073		
Laborer	0.191	1.528**	1.372
Artisan	0.195	1.230	0.987
Dummy=1 if in war had			
Diarrhea	0.267	0.593***	0.682***
Fever	0.215	1.299**	1.551**
Malaria	0.028	1.117	1.148
Measles	0.037	0.542***	0.738
Typhoid	0.048	0.595***	0.532***
Pneumonia	0.038	0.442***	0.430***
Bronchitis	0.047	0.349***	0.404***
Pleuritis	0.010	0.409***	1.097
Dummy=1 if population at enlistment			
<2,500	0.878		
2,500-25,000	0.072	0.865	0.711
25,000-50,000	0.008	0.351***	1.393
≥50,000	0.042	1.107	0.975
Dummy=1 if born in			
<1780	0.000		
1780-1800	0.001	0.278	0.199
1800-1820	0.045	0.630*	0.561*
1820-1840	0.546	0.776	0.820
≥1840	0.477	0.821	0.724
χ^2 for Log likelihood ratio		197.72***	126.93***
Percent concordant		65.8	66.9

***p<0.01, **p<0.05, and *p<0.1

The probability of death from TB is extended to recruits dying before 1875, 1895, and in the whole sample in order to increase the number of cases. Still, we considered the same list of

covariates.

Table 6. Probability of death from TB.

	Pr(Death=1) Before 1875	Pr(Death=1) Before 1895	Pr(Death=1) All years
	Odds ratio	Odds ratio	Odds ratio
Height (in m)	0.037***	0.081***	0.085***
Number of battles	0.997	0.964	0.980
Dummy=1 if in war			
Gunshot wounded	1.028	1.049	1.063
POW	1.038	0.959	0.950
Dummy=1 if occupation at enlistment			
Farmer	1.295	0.956	0.995
Professional			
Laborer	1.465	1.017	1.096
Artisan	0.754	0.635**	0.718***
Dummy=1 if in war had			
Diarrhea	0.802	0.921	1.016
Fever	1.475***	1.114	1.082
Malaria	1.604	1.174	1.027
Measles	0.665	0.799	0.874
Typhoid	0.838	0.874	0.803
Pneumonia	1.049	0.598***	0.640***
Bronchitis	0.435***	0.588***	0.510***
Pleuritis	0.506	0.826	0.776
Dummy=1 if population at enlistment			
<2,500			
2,500-25,000	1.028	0.874	0.767**
25,000-50,000	0.420	0.505*	0.581
≥50,000	0.617	0.864	0.861
Dummy=1 if born in			
<1780			
1780-1800	-	-	-
1800-1820	1.665	1.228	1.493*
1820-1840	1.172	1.070	1.193
≥1840	1.684	1.342	1.236
χ^2 for Log likelihood ratio	61.60***	74.66***	81.15***
Percent concordant	58.4	57.0	56.1

***p<0.01, **p<0.05, and *p<0.1

The diagnosis, discharge and death from tuberculosis are predicted, in a robust fashion, by height. After we control for the previously mentioned characteristics, taller recruits are less likely to suffer from tuberculosis and to die from it. The effect is substantial and very significative for morbidity and mortality during the war. Even when we extend the sample, height remains as a strong predictor of TB mortality.

War also imposed a heavy toll; recruits suffering from gunshot wounds were more likely to be diagnosed with tuberculosis, while an increase in the number of battles fought increased the probability of discharge. Both effects are significative providing support to the relation between war *stress* factors and TB morbidity. A recruit who received a gunshot wound was 50 percent more likely to be diagnosed with tuberculosis and the participation in an additional battle represented an increase in the odd ratio for discharge of 38 percent. Only laborers exhibit an increase in the odds of diagnosis. Bryder [3] finds a similar effect for more disaggregate occupations due to predisposition to the disease. Age also contributes to the progression or diagnose of tuberculosis. The cohort born between 1820-1840 (ages 20-40 at the beginning of the war) were less susceptible to the disease.

Physical symptoms of tuberculosis include fever, sweating at night, cough and difficult breathing, blood spitting and loss of weight; however, none of these symptoms is peculiar to TB; continued ill-health was probably the most constant symptom. Due to the symptoms, it is not surprising to find fever as a significant co-morbidity in tuberculosis diagnosis and discharge. However, fevers can be a consequence instead of a cause of TB; they predict the diagnosis (as a clinical sign) but they may not be a direct cause of the disease. The presence of respiratory diseases should increase the susceptibility to the infection; however, our results suggest a reduction in the probability of developing tuberculosis. A limitation in the diagnose helps explain this effect. When recruits were diagnosed with a respiratory disease they were either diagnosed with tuberculosis or one of the other major respiratory diseases (pneumonia, bronchitis or pleuritis); therefore a TB case would almost by definition not be diagnosed with pneumonia or any other respiratory disease. This limitation appears to be responsible for the reduced effect of the respiratory disease on tuberculosis. As the Medical History of the Civil War ([39], Vol. 6, 818) indicates: "Men were taken sick with diarrhea and dysentery, continued fevers, measles, bronchitis, pneumonia and other diseases, and their cases were reported under these headings. Months afterwards they

died or were discharged on account of tubercular disease of the lungs, although their names had never appeared in the list of those taken sick with consumption."

To analyze the time pattern of mortality, we study the recruit's waiting time until diagnose or discharge from tuberculosis by a Cox proportional hazard model. The timing of the diagnose or discharge is related to the same set of variables analyzed before, treating individuals who die from a cause of death other than TB as censored. However, in order to determine whether different conditions raised or lowered the risk of diagnose or discharge, we consider the prevalence of the different diseases as time-dependent covariates. In particular, to resolve causal ordering, we include the presence of the condition *before* tuberculosis but not the time interval prior to the diagnosis or discharge.

Diarrhea episodes prior to tuberculosis were significant predictors of the diagnosis of TB although it was the only condition that significantly provided *protection* against the disease. As Costa ([10], 13) notes, the pathway for such association is not clear since respiratory conditions and diarrhea were positively associated after controlling for enlistment characteristics. The risk of diagnose also increased (at a 10 percent level of significance) for recruits enlisted from towns with population between 25,000 to 50,000; but no recruits in that range were discharged due to tuberculosis. Farmers, laborers, and artisans had a lower risk of discharge from TB. At high significance levels, the risk ratio for farmers, laborers, and artisans was on average 0.5; that is the hazard of discharge for those occupations is only about half of the hazard for professionals (controlling for other factors).

Based on individual Census mortality data, Ferrie [15] also observes occupational differences in mortality from tuberculosis in 1850 and 1860. As he argues, the difference does not seem to correspond exclusively to income influences (through access to better food, shelter and sanitation) but to workplace factors. Farmers and laborers, notes Ferrie [15], experienced lower human-to-human contact required for the spread of tuberculosis although this precise mechanisms does not seem operative through the war. Since tuberculosis does not provide long-life immunity, even if farmers and rural residents were less exposed to the disease prior to the war, the advantages of city life discussed in Lee [23] cannot directly apply to tuberculosis.

Table 7. Hazard rates for days free from TB.

	Pr(Diagnose≤t)	Pr(Discharge≤t)
	Hazard ratio	Hazard ratio
Height (in m)	1.865	2.319
Number of battles	0.910	0.798
Dummy=1 if in war		
Gunshot wounded	0.716	0.506
POW	0.630*	1.386
Dummy=1 if occupation at enlistment		
Farmer	1.411	0.537*
Professional		
Laborer	1.046	0.468**
Artisan	0.992	0.458***
Dummy=1 if in war had		
Diarrhea	0.611***	0.945
Fever	0.895	0.780
Malaria	1.812	1.355
Measles	0.923	1.429
Typhoid	0.515	0.696
Pneumonia	0.937	0.626
Bronchitis	0.797	0.520*
Pleuritis	0.894	0.948
Dummy=1 if population at enlistment		
<2,500		
2,500-25,000	1.216	0.825
25,000-50,000	2.671*	-
≥50,000	0.939	0.300**
Dummy=1 if born in		
<1780	-	-
1780-1800	-	-
1800-1820	1.204	0.775
1820-1840	0.699	0.779
≥1840	0.803	0.943
χ^2 for Log likelihood ratio	32.04***	36.21***
χ^2 for proportional hazards[11]	28.19**	88.76***

***p<0.01, **p<0.05, and *p<0.1

To study waiting times until diagnose or discharge, we considered the length of time between

[11] We test the proportionality hazard assumption including and interaction of the regressors with log(time).

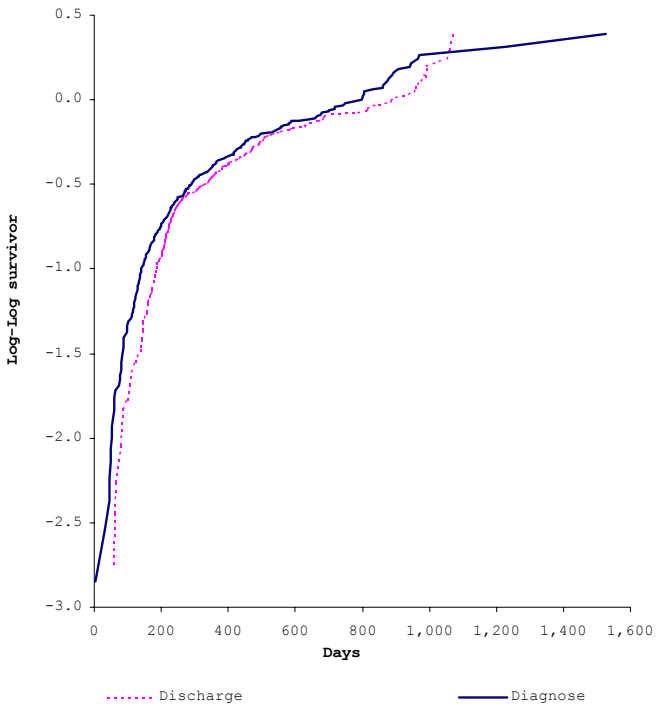

Figure 3: Log-Log survivor plots for diagnose and discharge.

incorporation to the Union Army and the diagnose and discharge date. Obviously, in our analysis recruits may have been observationally at risk prior to incorporation but the information in the Union Army prevent us to consider a more precise measure of days free from tuberculosis such as the point of acquisition of TB. As the Medical History of the Civil War ([39], Vol. 6, 818) notes: "[The] number of cases includes an unknown but certainly large percentage of individuals whose consumptive tendencies were so marked at the period of enlistment that they should not have been received into the service." In fact, as Table 4 shows, the first diagnosis of tuberculosis occurred just 3 days after the incorporation into the Army.

In addition, Figure 3 includes a representation of the survivor functions controlling for the effects of the previous characteristics. We construct the baseline survivor function for the sample mean of the covariates in order to estimate the Log-Log plot of survivors. For the middle part of the interval, the survivor function for discharge and diagnose are very similar; only in the extremes

the functions differ. As we noted before, diagnose started earlier in service and remained in use for longer periods compared to discharge.

6 Conclusions

Important *stress* factors contribute to the activation or acquisition of tuberculosis while in the Army. Recruits who experienced gunshot wounds or participated in more battles were more likely to suffer from TB. There is a relatively reduced probability for soldiers enlisted in cities with population in the range of 25,000 to 50,000 and a higher risk for laborers. More interesting is the fact that height reduces the probability of diagnosis, discharge and death. Taking height as a measure of nutritional status at early ages corroborates the importance of adequate nutrition for the reduction of prevalence and mortality from tuberculosis. The findings strengthen the association of increases in height with the reduction in susceptibility to infections and chronic diseases analyzed by Fogel [16]. Nevertheless, as Fogel [16] notes, the correlation of current food intake and morbidity is weakened by the presence of effects generated early in life. The number of days free from the disease is not very responsive to the *stress* factors mentioned above but it is affected by occupational characteristics. Farmers, laborers and artisans had reduced hazards for discharge from tuberculosis.

The findings in this paper also have implications for the current changes in TB morbidity analyzed by Raviglione et al. [32] among others. If the increase in prevalence of TB in developed countries represents higher progression rates from latent cases, the present study confirms the importance of *stress* factors responsible for more susceptibility to the disease.

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