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Heights of Men and Women in 19th-Century Bavaria: Economic, Nutritional, and Disease Influences

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We analyze heights of men and women who were imprisoned in 19th-century Bavaria. Heights were not significantly correlated by sex over time. Both men and women grew taller in milk- and potato-producing regions. Women's heights were significantly reduced by the 1840s potato crisis, tuberculosis prevalence, and illegitimate birth, none of which significantly affected men's heights. Economic factors in early childhood had more systematic influence on girls' than boys' heights and were more important than disease measures for both sexes. Conditions in the 1st year of life had greater effects on adult height than those in later years. © 2000 Academic Press

Understanding past standards of living is a common desideratum for economic historians. One variable that can illuminate such living standards is final adult height. Since stature is a function of conditions in youth, especially during early childhood, study of heights can indicate how children were treated in terms of nutritional quality and quantity as well as their disease and workload experience. Average adult height is nonetheless too blunt an instrument to measure *the* standard of living for a given society. If identifiable groups enjoyed markedly different standards of living, the ability to analyze their differential experiences

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as expressed by their heights would have considerable value. Differences in height by sex, for example, would be of great interest because inferring net nutritional conditions of a whole population from samples restricted to men involves obvious problems. This article presents evidence of differential influences on final adult height by sex.

Our samples consist of over 4100 records of men and women whose height was measured upon incarceration in mid- to late-19th-century Bavaria. While it is unlikely that these convicted criminals formed a representative sample of the Bavarian population, their usefulness should not be dismissed out of hand. Except for the rare sample of universally conscripted soldiers, every collection of heights was exposed to some sort of selection bias during its formation (Mokyr and Ó Gráda, 1996). Careful assessment of these potential biases can help determine whether patterns in height data were the result of selection processes or net nutritional factors. Since other research, primarily conducted by Stephen Nicholas and coauthors (Johnson and Nicholas, 1995; Nicholas and Steckel, 1991; Nicholas and Oxley, 1993; see also Riggs, 1994), has suggested the usefulness of prisoners' heights, it would be premature to ignore data from one of few places where men and women were measured in similar circumstances.

Apart from the specific study of differences by sex, our research also aims at extending our knowledge of central European heights. Twarog (1997) was mainly interested in the effects of industrialization in Württemberg, the region just to the west of Bavaria. While male heights generally trended upward there, short-term declines were also evident, indicating periods of hardship during industrialization. Komlos (1989) found diminishing heights during economic growth periods of the late 18th-century in central Europe. We aim to illuminate effects of modern economic growth and industrialization by explicitly testing whether changing real incomes, relative prices, and proxies for the disease environment were associated with variation in adult Bavarian heights.

Economy and Disease in 19th-Century Bavaria

A standard interpretation of Bavarian economic history through the 19th-century is that it lagged behind other regions in Germany, even the rest of southern Germany, in industrializing (Cameron, 1985, p. 13; Bosl, 1985; Grimm and Müller, 1985; and Zorn, 1975). Instead, stymied by widespread illiteracy, the Bavarian economy remained focused on subsistence agriculture. A revisionist literature finds this picture to be drawn too starkly (Preisser, 1993). Bavarian literacy rates were much closer to those elsewhere in Germany at the time than has been supposed.[1] By mid-century the proportion of the Bavarian workforce that was employed in industrial plants was greater than that in Hesse and nearly as great as that in Prussia. Growth in Bavarian industrial employment into the

[1] Lee (1977, pp. 356–383); apparently Cameron read Lee's estimate of 60% literacy as 60% *il*literacy. Cipolla (1969, p. 72) noted the achievement of relatively high literacy in Bavaria. See also Murray (2000) for other Bavarian literacy rates close to Lee's estimates.

second half of the century was brisk (Hamerow, 1966). While the Bavarian economy was centered on agriculture, its industrialization may have differed from that of the other German states in degree rather than in kind.

The predominant agricultural sector changed steadily over the period covered by our sample (Sandberger, 1978). At the beginning of the 19th-century much of the agricultural work force was bound into serfdom. About two-thirds of the Bavarian workforce toiled in agriculture at mid-century, well above the overall German proportion of 56% (Baten, 1999). From 1882 to 1907 the Bavarian proportion fell from three-fifths to one-half, a trend similar to that in the other regions (Tipton, 1974, pp. 978–979). If the shift from agriculture to industry had affected the net nutritional status of Bavarians, it should be reflected in heights of people born in Bavaria at that time.

A remarkable feature of the later 19th-century Bavarian environment was the disease burden imposed on Munich residents. By 1873 its population was 170,000 and growing, and growing just as fast was its reputation for filthy water, which brought cholera and typhoid fever. To clean up Munich, the public health professor and activist Max von Pettenkofer campaigned successfully to have a central abattoir built and fresh water piped into town from the nearby mountains (Angermair, 1992).[2] A sanitary sewage system was built at this time as well, inducing a sharp decline in typhoid mortality. The famous 1892 cholera epidemic that devastated much of Prussia, especially Hamburg, left Munich, and indeed the rest of Bavaria, untouched (Evans, 1990).

Many infectious diseases were endemic in 19th-century Bavaria. Pertussis was a prominent killer of young Bavarians, although death rates declined gradually over the century. Scarlet fever peaked in mortality in the 1860s, while measles mortality rates stagnated at generally low levels, with sharp increases during epidemics in the early 1850s and 1880s. Rigorous smallpox inoculation programs limited its incidence, except during the Franco-Prussian war of 1870–1871. Malaria was prevalent in the valleys of the rivers Danube and Altmühl. Tuberculosis was concentrated in the northeastern Franconian weaving districts. Typhus, finally, was a well-known visitor to Munich and the Danube regions, especially in the 1860s (Schwartz, 1933). These diseases were potential influences upon final adult height. While historical disease specific data is scarce, we integrate some rough measures of infectious disease conditions with our height data later in the present analysis.

The influence of disease and nutrition upon stature was an issue discussed in Bavaria at the time. According to the Bavarian physician Joseph Wolfsteiner, who was a contemporary of the prisoners in our sample, “Important evidence of the physical flourishing or decay of a population can be deduced by a thorough investigation of its heights... For humans, it is established that body size

[2] Pettenkofer, an enthusiastic foe of the germ theory of disease, is perhaps better remembered for his attempt to disprove the germ theory by drinking a glass of water densely contaminated with the cholera vibrio—with no ill effects.

diminishes when the physical or social environment worsens."[3] Why some environmental characteristics differed in their effects on the heights of men and women while others did not is not clear. Recovery and analysis of height data on women as well as men can potentially illuminate the effects of environmental conditions as experienced differently by men and women (Knodel, 1988; Klasen, 1998).

The Bavarian Prisoner Samples

Our sources of data were registers of arriving inmates at two Bavarian prisons, Wasserburg for women and Kaisheim for men.[4] Kaisheim was the largest of six prisons for men in Bavaria proper; Wasserburg was the smaller of the two prisons for women in the same area. The women's register covers the years 1860–1906, while the men in this sample entered prison during the years 1856–1908. While the records of female prisoners are reasonably complete, the male records are not. Due to the loss of male entrance books between 1867 and 1874 and between 1880 and 1906, our records are a subsample of all the prisoners at Kaisheim. The entrance books noted which prisoners were repeat offenders, easily enabling us to enter only the first of their height measurements and thereby avoid double counting. Because individuals begin to lose stature after about age 50, we discarded records of prisoners ages 50 and over. We also omitted those under age 18, as some of these people may have not reached their final height.[5] The samples ultimately analyzed here numbered 1582 men and 2546 women. The birth cohorts of these men and women extend from 1819 to 1885 for the women and from 1812 to 1886 for the men. Final adult heights of our sample members thus reflect conditions in Bavaria from the time of the Napoleonic and Revolutionary Wars into the late 19th-century for the later cohorts.

Using prison records to analyze stature involves trade-offs. One advantage over military records is the absence of minimum height requirements, which can bias height estimates. While the universe of human heights is distributed normally by sex, height minima often cause the left-hand tail of military height distributions to be truncated or eroded, and correcting for this deficiency can raise more questions than it resolves. On the other hand, nonmilitary samples of heights, such as those of students or prisoners, suffer from their own selection biases. Eighteenth- and 19th-century students tended to come from the middle and upper classes, while prisoners seem to have come from the working and lower classes. Our sample could suffer from three different sources of selection bias. First, it seems clear that rates of property crime, especially simple theft, were countercyclical; that is, property crime increased during hard times (Johnson, 1995). Second, these cyclical trends could have been more or less pro-

[3] Our translation from Anonymous (1860), *Bayern* (p. 445).

[4] For Wasserburg, see *Eingangsbuch I–III,* JVA Wasserburg, Staatsarchiv München. For Kaisheim, see *Eingangsbuch,* JVA Kaisheim, Staatsarchiv Augsburg.

[5] Prisoners born in the Palatinate were excluded.

nounced for women than men, and this difference itself could have changed over time. Third, institutional changes in the Bavarian prison system could have influenced the selection process for our samples.

With regard to the first, it is fortunate that the time period between 1856 and 1908 (when our offenders were incarcerated) can be characterized by relatively stable economic development. The only major crisis took place after the 1871–1873 boom. This crisis retarded growth for a few years, but it cannot be compared to the major crises of the early and mid-century. The years 1816–1817, 1831, 1845–1847, and 1853–1854 involved famines or at least food shortages and sharp declines in real income, whereas the 1873–1895 business downturn only meant slower growth rates. Although this slowdown of growth rates might have increased the numbers of incarcerated men and women, the number of male prisoners in all Bavaria was 2888 in 1873 and 2877 in 1894, while the number of imprisoned women actually declined from 395 to 293, a point to which we return below. In any case there seems to have been no noticeable trend in the share of the population that was incarcerated. The female rate fluctuated between 0.01 and 0.02% of the population and the male rate between 0.10 and 0.13%.[6]

Concerning the second issue, it is reassuring to note that, geographically, male and female crime rates were highly positively correlated (Johnson, 1995, pp. 151–155). Over time as well, Johnson notes (1995, p. 191), "the pattern of both female and male criminality did not change significantly in Imperial Germany despite the massive economic and social changes that took place there." This suggests that patterns in our data were more likely to stem from changes in the prisoners' net nutritional environments rather than from the selection processes that led them into our sample.

The third potential problem could have been caused by an institutional change in the Bavarian prison system. In 1873 the Wasserburg prison was transformed from a prison for minor crimes (*Gefangenenanstalt*) to one for more dangerous offenders (*Zuchthaus*). Thus, for example, 15 to 20% of entrants after 1873 had been convicted of murder, whereas there had been very few murderers before. This suggests the possibility that the selection process for criminals incarcerated in Wasserburg had changed. One could imagine that property crimes were more often committed by the poorer parts of the population, whereas murderers may have been more socially diverse. In any case the effect on height was negligible. Comparing average height of prisoners who entered before and after 1873 indicated almost perfect correlation among the overlapping birth cohorts.[7]

Class origins of the Bavarian prisoners were expressed in both their occupations and their crimes. Occupations clustered at the bottom of the socioeconomic scale. A large share of the men, some 38%, were described simply as servants (*Dienstknecht*) or day-laborers (*Tagelöhner*). Women's occupations were somewhat harder to interpret. For never-married women, the occupation in the record

[6] Generalbericht (1874, 1884, 1906). Palatinate excluded.

[7] Details of this comparison are available in an appendix from the authors.

TABLE 1
Industry of Employment for Prisoners and by 1882 Census (Listed as Percentages)

Industry	Men		Women	
	Prisoners	Census	Prisoners	Census
Agriculture	46.6	51.5	49.5	60.4
Farmers	4.7	35.9	4.6	42.3
Farm-laborers	40.8	14.7	44.1	17.5
Other	1.5	0.9	0.8	0.6
Industry	47.0	32.9	29.5	23.8
Metal	4.3	3.1	1.0	1.8
Textiles	3.2	2.6	0.5	2.8
Wood	4.4	3.6	2.5	2.1
Food	9.6	4.9	1.8	2.6
Cleaning	10.6	5.3	13.8	6.3
Building	9.1	6.1	3.8	3.7
Other	5.8	7.3	6.1	4.5
Service/other	4.5	7.8	17.4	10.2
Trade	1.7	3.7	3.7	4.4
Hotel/restaurant	0.9	1.2	4.8	2.3
Servant	0.2	0.4	6.3	1.3
Other service	1.7	2.5	2.6	2.2
Officials/professional	1.2	6.6	1.6	3.7
No occupation	0.3	1.2	1.3	1.9

books was their own; for married and widowed women, the recorded occupation was that of their husband. Among the never-married women, half were also servants (*Dienstmagd*) and another quarter (24.2%) were seamstresses (*Näherin*) or day-laborers. The wives and widows were married to men of many different occupations: 176 distinct job titles among 750 ever-married women. The only category accounting for more than 5% of the husbands was day-laborer, at 25.6%.[8]

Table 1 shows the distribution of prisoners according to industry of employment, so as to be comparable to information in the 1882 Imperial census. The census counted women's employment as above; that is, the category marked "women" actually includes industries in which husbands of the married and widowed women worked. For both sexes, farm-laborers were overrepresented while landowning farmers were underrepresented. For men, prisoners employed in industry were disproportionately many as were women in service-related employment. For both sexes, relatively few prisoners had held white-collar jobs.

Crimes committed by the Bavarian prisoners coincide with the notion that

[8] Regressions with occupational measures as dependent variables showed no change in the probability that a prisoner was of the lower classes over time.

TABLE 2
Distribution of Crimes by Sex, Bavarian Prisoners

Crime	Men		Women	
	Number	Percentage	Number	Percentage
Theft and fencing	998	62.5	1516	59.5
Robbery	116	7.3	2	0.08
Assault	110	6.9	19	0.75
Bribery	30	1.9	0	0
Rape, procuring, and other sex offenses	89	5.6	63	2.5
Forgery, extortion, fraud, counterfeiting	122	7.6	241	9.5
Murder and manslaughter	119	7.5	431	16.9
Abortion and infanticide	0	0	89	3.5
Other	12	0.8	188	7.4
Total	1596	100	2549	100

these people lived on the margins of the economy and stole out of need. Table 2 shows that a majority of both men and women were imprisoned for theft or handling stolen goods. During the period covered by our samples, historians of Bavarian and Imperial criminality have consistently found strong positive correlations between food prices and theft rates.[9] Circumstantial evidence thus points to our samples as consisting mostly of the poor, the peasants, and the workers, who occasionally stole to make ends meet.

The composition of the samples changed over the years covered, generally in ways consistent with the written record of Bavarian history. Table 3 shows the percentages of the sample falling into each of several categories by birth cohort. As an artifact of our sampling process, the earlier birth cohorts for both men and women consist of older prisoners and the later cohorts consist of younger people. The proportion of urban-born Bavarians increased over the course of the 19th-century, and this was reflected in our sample, except for the rather small cohort of women born after 1880. A noteworthy aspect of Bavarian social history at this time was a marked rise in illegitimacy in the middle of the century, following legal changes that let local authorities withhold permission to marry from couples thought to lack sufficient wealth to become self-supporting. The share of prisoners who were born to unmarried parents follows this trend, at levels similar to those found in other studies of this period (Baten and Murray, 1997). Finally, the share of prisoners who could roughly be defined as middle class, based on their own or their husband's occupations, showed no real trend.

[9] Johnson (1995, p. 140) cites the work of Blasius, Zehr, and Woytinsky and notes (p. 117) the quality of Bavarian criminal records: "the most highly developed crime statistics of any German state prior to 1882."

TABLE 3
Composition of Bavarian Prisoner Sample by Birth Cohort:
Percentages by Age, Urban Birth, Illegitimacy, and Class

Men

Variable	Birth cohort 1812–1829	1830s	1840s	1850s	1860s	1870s	1880s
Age <30	0	34.6	59.4	72.8	36.4	54.8	100
30 ≤age<39	47.7	44.4	34.9	16.3	37.7	45.2	0
40 ≤age	52.3	21.0	5.7	10.9	25.9	0	0
Urban born	7.9	9.0	7.2	6.9	11.7	15.8	24.1
Bastard	24.1	42.6	36.7	42.1	27.8	21.9	24.1
Middle class	10.6	6.2	5.7	7.9	10.5	11.0	12.7
Total	216	390	401	202	162	146	79

Women

Variable	Birth cohort 1819–1829	1830s	1840s	1850s	1860s	1870s	1880s
Age <30	0	6.6	68.3	60.9	50.4	72.8	100
30 ≤age<39	5.7	68.8	22.5	18.1	36.4	27.2	0
40 ≤age	94.9	24.6	9.1	21.0	13.2	0	0
Urban born	7.7	10.2	7.5	11.5	15.1	17.7	12.5
Bastard	28.2	30.8	36.4	37.5	32.6	26.7	31.9
Middle class	10.3	11.7	4.9	11.7	9.7	7.0	9.7
Total	195	529	799	453	258	243	72

Influences on Male and Female Heights at the Individual Level

We employed ordinary least-squares regression analysis to distinguish among age, cohort, nutrition, disease, and other social effects on final adult height. Table 4 provides mean values of the variables used in the regressions. The two distributions are quite similar in terms of these descriptive variables. In each group about six-sevenths were ages 24–49, a tenth were natives of cities, and about a third had been born illegitimately. Agricultural productivity, as expressed by per capita output of milk, grain, and potatoes in the region of birth, differed little between the sexes. Thus it seems unlikely that differences in heights between the men and women stem from compositional differences in the two samples.

Mean heights by sex indicate that the net nutritional environment of the Bavarian prisoners was much worse than that faced by modern Westerners but typical of men at least of their day. The mean male height of 167.2 cm would place the typical Kaisheim prisoner in the 7th centile of modern American standards (Steckel, 1996). The average Kaisheim prisoner was slightly taller than the average soldier in contemporary Bavarian military samples, for whom average height of 166.3 cm for cohorts born between 1820 and 1850 and of 165.0 cm

TABLE 4
Mean Values of Variables Used in Regression Analysis

Variable	Men		Women	
	M	*SD*	*M*	*SD*
Height	167.24	6.32	156.12	5.78
Milk production (liters per capita)	241.31	96.42	261.17	105.71
Grain production (kg per capita)	229.01	98.05	209.65	89.06
Potato production (kg per capita)	172.79	76.74	165.10	80.44
Tuberculosis death rates by sex (per 100,000 persons)	219.07	49.20	197.36	35.60
Urban	0.10		0.11	
Middle class	0.08		0.09	
Illegitimate	0.34		0.33	
Age 21	0.04		0.04	
Age 22	0.04		0.06	
Age 23	0.05		0.05	
Ages 24–49	0.87		0.85	
Born 1810–1819	0.02		0.002	
1820–1824	0.05		0.02	
1825–1829	0.08		0.06	
1830–1834	0.11		0.08	
1835–1839	0.15		0.14	
1840–1844	0.13		0.15	
1845–1849	0.09		0.18	
1850–1854	0.08		0.10	
1855–1859	0.04		0.07	
1860–1864	0.04		0.05	
1865–1869	0.07		0.04	
1870–1874	0.05		0.05	
1875–1879	0.04		0.04	
1880–1884	0.04		0.02	
1885–1889	0.01		0.003	
N	1582		2546	

for those born in 1854 were estimated (Baten, 1999; Floud, 1994). Other samples of central European heights during the same period fall in a similar range. A relatively short set of contemporary men can be found in Komlos's (1989) sample of mid-19th-century Moravians and Bohemians, at about 166 cm. Twarog (1997) estimated male heights in Württemberg for soldiers born between 1852 and 1893. Working-class heights were estimated to be around 164 cm, heights of men from the agricultural population were around 166 cm, and those of the upper class around 170 cm (Twarog, 1997, p. 300). At 156.12 cm the average Wasserburg woman would fall in the 9th centile of modern American standards (Steckel, 1996). The standard deviation of the men is quite similar to that obtained in other samples of adult men at 6.43 cm.

Table 5 presents estimates of two ordinary least-squares regressions, with

TABLE 5
OLS Regression Estimates

Variable	Men		Women	
	parameter est.	*SE*	parameter est.	*SE*
Constant	149.53***	7.20	143.50***	4.95
Milk production	0.12**	0.046	0.089***	0.030
Milk squared	−0.00017**	0.000073	−0.00012***	0.000047
Potato production	0.050***	0.020	0.028*	0.017
Potato squared	−0.000053**	0.000025	−0.000025	0.000022
Bread grain prod.	−0.061**	0.024	−0.017	0.016
Bread grain squared	0.00012**	0.000048	0.000034	0.000034
Tuberculosis death rate	−0.0012	0.0045	−0.012**	0.0050
Potato famine	0.00085	0.0065	−0.011***	0.0039
Born in Munich	0.30	0.96	−1.20**	0.57
Born in other urban area	−1.88**	0.79	0.35	0.55
Middle class	1.36**	0.59	0.50	0.38
Illegitimate	−0.23	0.27	−0.82***	0.24
Age 18	−3.49**	1.66	−2.09	1.48
Age 19	−2.00	1.43	−0.19	0.81
Age 20	−2.39**	1.02	−1.41**	0.66
Age 21	0.094	1.08	−0.61	0.57
Age 22	−1.52*	0.92	0.049	0.47
Age 23	−0.88	0.82	−0.34	0.55
Born 1810–1819	2.64**	1.04	1.22	2.09
1820–1824	1.01	1.10	−0.11	0.76
1825–1829	1.12	0.94	−0.11	0.63
1830–1834	1.24	0.88	−0.37	0.53
1835–1839	1.14	0.83	−1.23**	0.51
1840–1844	0.98	0.84	−0.87*	0.50
1845–1849	1.03	1.43	1.57**	0.76
1850–1854	0.91	0.97	−0.033	0.53
1860–1864	0.80	1.01	2.07***	0.63
1865–1869	−0.17	0.96	1.29**	0.64
1870–1874	1.65*	0.92	1.09	0.68
1875–1879	2.33**	1.01	1.36**	0.68
1880–1884	1.64	1.16	1.79**	0.90
1885–1889	2.74*	1.55	−0.038	1.23
R^2	0.04		0.05	

Note. Omitted categories include ages 24–49, born to married parents in rural area of Upper Bavaria South region during 1855–1859, and lower class. The dependent variable is the height of individual in centimeters. White tests indicated heteroskedastic errors in the men's regression ($\chi^2 = 398$; $p = 0.004$) and in the women's regression ($\chi^2 = 380$; $p = 0.03$). Estimated standard errors in the regressions are heteroskedasticity-consistent.

* Significantly different from zero at 0.10 level.

** At 0.05 level.

*** At 0.01 level.

height as the dependent variable. The independent variables can be classified into four groups: age, gross nutritional availability and disease-related variables, social characteristics, and birth cohorts. White tests indicated the presence of heteroskedastic errors, so heteroskedastic-consistent standard errors were estimated. Dummy variables for age at measuring suggest that the growth process may have continued for sample members past the usual ages of cessation. Among the men those aged 18, 20, and 22 were significantly shorter than those in the omitted category of 24 to 49 years old, which suggests that men may have continued growing into their early 20s, a sign of poor net nutrition consistent with their average stature that was short by modern standards. Likewise, the significant coefficient of the age 20 variable in the women's regression suggests that women may have continued growing well past age 18, again a sign of poor net nutritional conditions.

One valuable characteristic of the Bavarian prisoner data sets is the capability of distinguishing among the effects of nativity in the several regions. These regions differed notably in the composition of their agricultural output. While some emphasized milk and dairy products in their production mix, others concentrated on potatoes and still others on bread grains. Surveys from the mid-century allowed us to assign each observation values that represented per capita agricultural production levels in their birth region: milk production as of 1840, potato production as of 1853, and bread grains also as of 1853 (no author, 1854–1859; see also Baten, 1999 for further explanation). To model potential nonlinearities and substitutabilities we used both linear and quadratic terms for the food-production variables.

Food production–adult height relationships were strongly nonlinear in the men's case while mixed in the women's case. For both men and women there was an optimal (in height terms) amount of milk production in their birth region; but for both men (353 liters) and women (371 liters) the optimum occurred at a standard deviation above average production levels. Availability of protein from dairy sources may thus have been a binding constraint in the growth process, even if subject to diminishing returns above a large production level. A similar pattern emerged for the effect of potato production on men's heights. The optimal production level of potatoes was far above the average. The relationship between women's heights and potato production was linear, positive, and significant, while bread grain production was unrelated to women's heights. Overall, we find that food production in the prisoner's birth region was generally positively related to final adult height, but in a complex and nonlinear relationship.

Because one of the best known and most obvious symptoms of tuberculosis is its wasting effect on the body, hence the archaic name of "consumption," we investigated possible relationships between the prevalence of the disease and final adult height. We assigned to each observation the cause-specific mortality rate from tuberculosis in the prisoner's home region as found in a survey of

1872.[10] A significant effect of tuberculosis rates on final adult height was seen only among women, and it was small but nontrivial in magnitude. A 1-standard-deviation difference in tuberculosis death rates for women was associated with a difference in heights of approximately 0.43 cm. It should be noted that in the case of tuberculosis the direction of causality is unclear. Coping with the symptoms of active tuberculosis before the cessation of growth would consume a substantial number of calories, which suggests that tuberculosis could cause diminished stature. However, the lower nutritional status that would induce shorter stature also would increase susceptibility to tuberculosis. We cannot distinguish between the two in the case of the Wasserburg prisoners.

We used the information on the prisoner's birthplace, parents, and occupation to construct regressors that approximated the person's social situation broadly defined. Again, we found differences by sex in the effects of independent variables on final adult height. Birth to unmarried parents carried serious consequences for the quality of care experienced by girls. In the entire sample, only girls experienced sufficient deprivation to result in a significant shortfall in adult stature. The dummy coefficient for illegitimate birth for boys was also negative, but not significant.[11] Since illegitimate children were typically raised in straitened circumstances, this finding suggests that girls born out of wedlock received particularly spartan care, more so than did boys. Regarding urban effects, the prisoner's birthplace was categorized as either Munich, another city of more than 5000 inhabitants as of 1852, or elsewhere. Effects of urban birth varied by sex. Birth in Munich depressed final adult height relative to rural birth for women but not for men. Those men born in urban areas other than Munich had final adult heights nearly 2 cm less than the rural born, but women born in other urban areas were unaffected. Due to relative immobility across classes, a variable for class based on the prisoner's (or husband's) occupation is a reasonably good proxy for resources available to the family in which the prisoner had been raised (Lundgreen, Kraul, and Ditt, 1988).[12] While middle-class status was in fact associated with greater height for both sexes, the effect of class on final adult height was only significant for boys. Thus, middle class status enhanced boys' net nutritional status, while girls received about the same treatment regardless of class.

Narrative histories relate occasional years of bad harvests such as those of 1845–1847, when potato crops across northern Europe succumbed to blights and

[10] *Beiträge zur Statistik des Königreichs Bayern 33* (1878). The unusual pattern of higher death rates for men is consistent with earlier Bavarian data in the same publication vol 8 (1859).

[11] While the illegitimacy dummy for males was not significant for the entire sample as shown in Table 5, regressions restricted to members of successive birth cohorts indicate a pattern in shortfall of male bastard heights strikingly similar to those among females: no shortfall among the early birth cohorts, a significant shortfall of about 2.5 cm in the cohorts of the 1850s and 1860s, and then an insignificant shortfall again. Presumably this pattern reflects changes in the tolerance level toward illegitimately born boys in ways similar to those described in Baten and Murray (1997) for girls.

[12] Recall that own occupations were given for male and never-married females, and husband's occupation was given for married and widowed females.

bad weather. The dummy variable "potato famine" measures the effects of this nutrient supply shock in the regions of Bavaria most dependent upon potato production for nutrition. It is an interaction variable in which potato production per capita in the subject's region of birth was multiplied by a dummy variable set equal to 1 for birth during the years 1845–1849. The coefficient of this variable was significant for females but not for males, suggesting that very young girls may have borne the burden of the food shortage. A 1-standard-deviation difference in potato production in relatively good times, among those girls born during the later 1840s, was associated with a 0.88-cm shortfall in adult height. Our ability to detect this shock in adult heights of women is a combination of the effects of the shock and the later net nutritional environment experienced by these prisoners. It is possible that males in this birth cohort were also nutritionally deprived during this period, but that they "caught up" in growth during later, better times. The Bavarian women prisoners from the potato-dependent districts apparently did not benefit from such improvements later in life, so the insult of the famine years remained a part of their anthropometric record.

The usefulness of heights is generally discussed in terms of average height in a large sample, yet the discussion above considered each individual man or woman as one observation. In the case of individuals, of course, final adult height is heavily influenced by genetic factors. As a result a set of regressors with several significant coefficients might still explain just a small part of the variation in individual heights—here, that proportion is only about 5% according to R^2 estimates for both regressions. While that is a typical R^2 for regressions that analyze height of adult or near-adult subjects as the dependent variable, it may seem low in absolute terms, as it leaves a considerable amount of variation unexplained. In order to analyze the average heights in groups of sample members, as well as to explore aspects of dynamic trends, we aggregated heights of sample members into 1-year birth cohorts and conducted a time series analysis.

Time Series Analysis of Bavarian Heights

We aggregated the individual cases by birth year and reduced both samples by omitting those born before 1820 and after 1880. We also omitted males and females below age 23. The resulting series consisted only of men and women who had attained their final adult height, and the cohorts in each series consisted of a reasonable number of heights to form an average for each cohort. Figure 1 shows trends in heights over the period of the sample using a 5-year moving average. No correlation between male and female is evident. We consider causes of the various trends in these series of heights.

Consistent time series of several relevant variables are available for 19th-century Bavaria. Since height is a function of quality and quantity of gross nutrition and adverse effects of disease and workload, we consider the relative impact of factors such as disease, quality of infant care, and nutritional avail-

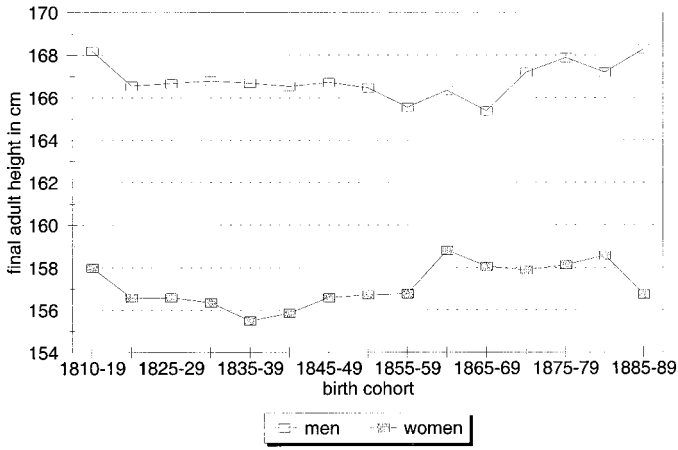

FIG. 1. Height trends by sex and birth cohort in 19th-century Bavaria.

ability. Infant mortality rates (IMR) are a valuable measure of the disease environment and quality of infant treatment, so we use infant mortality rates published in the official Bavarian statistical abstracts.[13] A series of real wages estimated for Bavarian building tradesmen represents economic conditions, which includes the availability to purchase foodstuffs (Gömmel, 1979, pp. 211–220). These wages correlate strongly with a shorter series of male and female unskilled wages published in Gerhard (1984) and so appear to be representative of Bavarian earnings at the time. As a proxy for the quality of nutrition in terms of protein availability, we used the price of milk deflated by an index of all food prices (Gömmel, 1979, pp. 216–220). Presumably, the greater this real price, the more expensive were high-protein foods, with negative consequences for growth prospects. We focus on conditions during infancy and early childhood because auxological research indicates that the first 3 years heavily influence one's height path (Eveleth and Tanner, 1990). Recent research with distributed lag models similar to those presented here also found that final heights were not significantly influenced by conditions after age 3 (Baten, 2000).

To determine the stationarity of each series, we conducted standard Augmented Dickey–Fuller (ADF) tests. The purpose of ADF tests is to check for the presence of a unit root in each series or jointly a unit root and time trend. A series without a unit root is said to be stationary. Regressing one nonstationary series on another nonstationary series increases the probability of inferring a spurious relation. ADF tests use a standard t statistic to test for nonstationarity, but these tests require a special table of critical values, as the distribution of this t is nonstandard. Autocorrelated errors produce inefficient estimates of the coeffi-

[13] For 1820–1860, see *Zeitschrift d. Kgl bayr. Stat. Bureaus* (Vol. 9) (1861); for 1861–1879, see the 1898 *Zeitschrift* (Vol. 30).

TABLE 6
Time Series Diagnostics: Augmented Dickey–Fuller Tests

Equation estimated: $\Delta y_{t-1} = \alpha + \beta t + \gamma y_{t-1} + \text{lags of } \Delta y$				
Variable	F for $\beta = \gamma = 0$	t for $\gamma = 0$	DW	Number of lags
Women's heights	10.46***	−4.55***	1.94	1
Men's heights	8.03**	−3.99**	2.07	1
IMR	26.96***	−7.33***	1.91	0
Real wage	6.26*	−3.28*	1.97	4
Real milk price	11.38***	−4.77***	1.93	1
LFPR	7.55**	−3.88**	1.89	2

Note. F from Enders (1995, p. 421); t from (MacKinnon (1991); all DW statistics for ADF tests indicate no serial correlation among errors.

* Significantly different from zero at 0.10 level.

** At 0.05 level.

*** At 0.01 level.

cients used in this t test, so lagged values of differences are added to the right-hand side of the regression in order to reduce the error term to nonautocorrelated white noise. The number of lags was chosen to be the smallest that led to nonautocorrelated errors, according to the Durbin–Watson test (Enders, 1995). Table 6 presents the results of the ADF tests. All series were found to be free of unit roots, so that standard OLS regression using these series is permissible. ADF tests that reduce the residuals to white noise clearly reject nonstationarity. Testing for trend and unit root also results in rejection of the null in the same fashion as for tests of unit roots alone (Enders, 1995). Thus, OLS regressions may be used to examine influences on average heights of cohorts, without undue concern that inferences may be spurious.

Table 7 presents the results of these regressions in three panels. In Panel A, the dependent variable was the average adult height of the cohort of prisoners born in a given year. The independent variables were the real wage, real price of milk, and infant mortality rates in that year. Thus, Panel A presents estimates of the effects of conditions in infancy upon final adult height. The results are intriguing. For both men and women, real wage rates during their 1st year of life were positively and significantly associated with greater adult height. The implication is that economic conditions have a consistently important effect on final adult height. The real price of milk, while negatively related to average adult height for both sexes, was significant only for women. Women's heights seem to have been systematically influenced by the availability of relatively cheap protein in ways that men's heights were not. The effect of infant mortality rates upon adult height differed significantly by sex, and by about the same magnitude. For women, greater infant mortality led to taller adult women on average while the opposite was true for men. Given the well-established hardiness of girl babies during infancy relative to boys, the infant mortality–height relationship is puzzling and deserves further research.

TABLE 7
Time Series Regression Results

Dependent variable (adult height)	Males		Females	
	Parameter est.	Standard error	Parameter est.	Standard error
Panel A: Effect of conditions in 1st year of life on average final adult height				
Intercept	170.19***	2.86	149.15***	2.61
Real wage	0.05**	0.02	0.07***	0.02
Milk price	−0.01	0.01	−0.03***	0.01
Infant mortality	−0.02**	0.01	0.02**	0.01
DW	1.99		1.89	
R^2	0.16		0.37	
Panel B: Effect of conditions in 2nd year of life, controlling for 1st-year conditions				
Intercept	172.34***	3.47	147.21***	3.25
Real wage (year 1)	0.01	0.04	0.08**	0.04
Real wage (year 2)	0.06	0.04	−0.02	0.04
Milk price (year 1)	−0.01	0.01	−0.03***	0.01
Milk price (year 2)	−0.001	0.01	0.01	0.01
IMR (year 1)	−0.02*	0.01	0.02**	0.009
IMR (year 2)	−0.01	0.01	0.004	0.009
DW	2.06		1.85	
R^2	0.23		0.38	
Panel C: Effect of conditions in 3rd year of life, controlling for 1st- and 2nd-year conditions				
Intercept	176.20***	3.73	147.55***	3.62
Real wage (year 1)	0.01	0.04	0.09**	0.04
Real wage (year 2)	0.07	0.06	0.02	0.05
Real wage (year 3)	−0.01	0.05	−0.04	0.04
Milk price (year 1)	−0.02	0.01	−0.04***	0.01
Milk price (year 2)	0.01	0.02	0.005	0.02
Milk price (year 3)	−0.01	0.01	0.01	0.01
IMR (year 1)	−0.002	0.01	0.02	0.01
IMR (year 2)	−0.01	0.01	0.004	0.01
IMR (year 3)	−0.02**	0.01	0.003	0.01
DW	1.89		1.89	
R^2	0.31		0.41	

In both regressions the R^2 was much greater than in the individual-level regressions, although well short of suggesting that the models explain even half the variation in average heights. These models explain a much greater proportion of variation in *average* adult height than did the previous regressions that used *individual* adult height as the dependent variable, thus justifying this research strategy. By this standard, conditions in the 1st year of life explained much more of the variation in female height (37%) than in male height (only 16%), perhaps

suggesting that female heights were more systematically dependent upon these net nutritional conditions than were male heights.

Panels B and C attempt to assess effects of conditions in the 2nd and 3rd years of life upon final adult height. In each panel independent variables are arrayed as in a distributed lag model (with equal weights) so as to see the effects of a given year's conditions holding prior conditions constant. As in Panel A, women's heights were far more systematically related to economic and nutritional conditions than were men's. The R^2 estimates in the women's regressions were consistently greater, and the men's regressions had only one significant coefficient in each panel. To be sure, the men's regressions may have been subject to some multicollinearity, as suggested by the increasing R^2 with the increased number of variables combined with few significant coefficients. In each case for women, the introduction of variables to represent conditions in the cohort's 2nd and 3rd years of life had little power to explain variation in final adult height. Instead, real wages and the real price of milk in that first year of life continued to explain significant variations in final adult height. It appears that the net nutritional condition of girls in 19th-century Bavaria was heavily dependent upon conditions during infancy, while that was less true for boys. For both sexes conditions in the 2nd and 3rd years of life had much less influence upon final adult height.

Comparisons and Conclusions

This article extends anthropometric history in several different directions. While there are existing studies of British prisoners, we have examined comparable samples of men and women on the Continent. Parallels emerged at the individual level among the prisoners of England, Scotland, and Bavaria. For example, in all three studies, birth in cities affected males more than females. Riggs (1994) found that among male Scottish prisoners, Glasgow natives were more than an inch shorter than other prisoners. Female Glaswegians, however, were only a fifth of an inch shorter than other women. Johnson and Nicholas (1995) found smaller differences of an eighth to a fifth of an inch among those prisoners tried in urban counties of England, which presumably correlated with urban birth; but even in this case the male difference was statistically significant while the female difference was not. The Bavarian picture is more complex than that presented by the British prisoners. Among the Bavarian prisoners, men born in medium-sized cities were almost 2 cm shorter than men born in rural areas, while women were more affected by birth in Munich than were men. The unavoidable disease environment was worse in towns than in rural areas and may have affected boys more severely than girls, but the effect of Munich birth on women but not men is puzzling.

Over time, trends in heights by sex present an equally complex picture. Among the Bavarian prisoners, no clear correlation between sexes can be seen in either Fig. 1 or in the coefficients of birth cohort variables in Table 7. By contrast,

heights by sex of successive English birth cohorts correlated closely. Among Scottish heights, birth cohort coefficients for men and women were positively but not significantly correlated, more like the Bavarian case. Particular cohort effects uncovered by Johnson and Nicholas included a distinct downturn for both men's and women's heights during the "hungry forties." In Bavaria, women born in potato-dependent districts during the brief period of the famine suffered diminished heights. Bavarian men in this cohort were either unaffected or they experienced catch-up growth at a later date. Time series analysis of average heights by birth cohort showed that final adult height of women responded much more systematically than did men's heights to differences in economic, nutritional, and disease conditions in infancy. Whether the reason for this was that boys were shielded from variation in these conditions by their parents while girls were relatively exposed to them cannot be determined, but remains a subject for further research.

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