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Heights and Real Wages in the 18th and 19th Centuries: An International Overview

Introduction

When economic historians first became interested in the study of human stature during the 1970s, they hoped to find a proxy for income that would allow estimates for time periods and regions that could not be studied otherwise. They employed the finding of human biologists that average (not individual) human stature was influenced by the quality of nutrition, the disease environment and physical exertion. As people experiencing income growth usually tend to buy better food and medical goods for themselves and their children, a close correlation between average height and GDP was expected.[2] However, the main advantage of empirical research is the possibility to find the unexpected: It turned out that under certain conditions, people born in poorer regions became taller, and during some phases of substantial GDP growth, heights in fact declined, for example in the USA and Britain between the 1820s and 1840s.[3] This article compares height and real wages in Germany, The Netherlands, Sweden, France,

[1] I wish to thank to John Komlos, Timothy Cuff, Michael Haines, John Murray, Richard Steckel and participants of the 1997 SSHA session on 'Biological Wealth of Nations' in Washington for helpful comments.

[2] For recent overviews see *J. Komlos /J. Baten (eds.)*, The Biological Standard of Living in Comparative Perspective. Stuttgart 1998; *R. Steckel/R. Floud (eds.)*, Health and Welfare during Industrialisation. Chicago and London 1997. "Genetic" determinants are less and less regarded as powerful explanations, see for an overview: *J. Baten*, Ernährung und wirtschaftliche Entwicklung in Bayern, 1730-1880. Stuttgart 1999, pp. 21-37; genetic height differences are not visible in France after controlling for economic variables, see *J. Baten*, Kartographische Residuenanalyse am Beispiel der regionalökonomischen Lebensstandardforschung über Baden, Württemberg und Frankreich, in: *D. Ebeling* (Hg.), Historisch-thematische Kartographie. Konzepte - Methoden - Anwendungen. Bielefeld 1999 (in print), pp. 98-109.

[3] *J. Komlos*, Shrinking in a Growing Economy: the Mystery of Physical Stature during the Industrial Revolution, in: Journal of Economic History 58, 3, 1998, pp. 779-802; *J. Komlos*, The Secular Trend in the Biological Standard of Living in the United Kingdom, 1730-1860, in: Economic History Review 46, 1, 1993, pp. 115-144.

Austria and Britain in order to see if this "Early Industrial Growth Puzzle" also applies to other countries in the 18th and 19th centuries.

The puzzle led to more research on the influence of the disease environment and public hygiene, because rising incomes and catastrophic hygienic conditions often coexisted in the large industrial towns, such as Manchester or New York.[4] Feinstein recently reduced the unexplained gap between height and income growth in the 1830s and 1840s for the English case: he estimated that real earnings (adjusted for unemployment, number of dependants and urban disamenities) were probably stagnating, not rising.[5] But still, the unexplained gap has led several scholars to suggest that a nutrition-independent influence of the disease environment mainly determined changes in height over time. While this factor might have contributed to the decline in heights, this article argues that real wages and other economic variables (such as the relative price of animal proteins) had a stronger impact.

We first discuss the relative influence of GDP and real wage on heights, and then proceed to address a methodological issue: many European samples consist of 19- or 20-year-old conscripts who were still growing at the time they were measured. It is important to clarify, whether the influence of economic conditions in the years preceding measurement, or the influence of the years following birth had the biggest influence on height at the time of measurement.[6] The third and fourth sections compare height and real wages for the 18th and 19th centuries respectively. Section 5 explores

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[4] There are other factors that have an impact on height, see *Komlos*, Shrinking.

[5] Charles Feinstein, "Pessimism Perpetuated: Real Wages and the Standard of Living in Britain during and after the Industrial Revolution," in: Journal of Economic History 58, 3, 1998, pp. 625-658.

[6] More precisely: if height H is measured at age 19 at time t and real wages are denoted by W, then are H_t and W_{t-1} more highly correlated, or H_t and W_{t-19}.

the influence of real wages on heights and the potential influence of the disease environment (proxied by infant mortality rates), and section 6 concludes.

1. Real wages and real income per capita

The traditional measures of the standard of living include real wages and real GDP per capita. For the 20th century, real GDP per capita was found to be closely correlated with anthropometric measures, provided the income distribution was controlled for.[7] For prior centuries, however, we have only scattered data on both GDP and income distribution. As most studies are on lower class heights in this epoch, one would expect real wages in lower class occupations to be more closely correlated with height than with GDP, particularly without controlling for shifts in the income distribution. The real wage variable has the additional advantage to be available for a number of countries in the 18th and 19th centuries for which no GDP series have been estimated. For Germany, no annual data are available prior to 1850, and the series for 1850-1900 is still under debate.[8] For the Dutch case, Horlings and Smits showed that real wages and real income per capita deviated considerably from one another in the 19th century, as the commercial gains from colonial activities boosted GDP, but the additional income was unevenly distributed and did not show up in real wages. Hence, it had little influence on the nutritional status of the poorer segments of the

[7] The following studies showed this empirically: *R. Steckel*, Height and Per Capita Income, in: Historical Methods 16, 1, 1983, pp. 1-7; *H. Brinkman/J. W. Drukker*, GDP per Capita and the Biological Standard of Living in Contemporary Developing Countries, in: *Komlos/Baten*, Biological, pp. 55-89; R. Steckel, Stature and the Standard of Living, in: Journal of Economic Literature 33, 4, 1995, pp. 1903-40.

[8] *Fremdling,-Rainer*, German National Accounts for the 19th and Early 20th Century, in: Scandinavian Economic History Review 43, 1, 1995, pp. 77-100. *A. Ritschl/M. Spoerer*, Das Bruttosozialprodukt in Deutschland nach den amtlichen Volkseinkommens- und Sozialproduktsstatistiken, in: Jahrbuch für Wirtschaftsgeschichte 1997, 2, pp. 27-54.

population.[9] Average real income per capita increased nearly at a constant rate during the 19th century, while real wages failed to do so until the 1850s. To be sure, afterwards they did reach the growth rates of GDP.

Real expenditures per capita of course includes many components that are not directly related to nutrition, such as financial services, while real wages - at least up to the middle of the 19th century - were relevant, in the main, for the poorer segments of the society, whose income elasticity of demand for food was relatively high. [10] Hence, fluctuations in real wages would have had a larger impact on food expenditures than those of real income (in wealthier economies, clothes and other consumption goods had a more substantial influence). Perhaps an even closer correlation with height might be expected with nominal wages divided by food prices, particularly if dairy and animal products were given a larger weight than warranted, insofar as (a) animal protein was particularly scarce and expensive in Europe before the 20th century, and (b) the income elasticity of demand for such food items tends to be higher than for carbohydrates.

2. The effects of birth year (BY) and the years before measurement (YBM) on height

A significant methodological question that has not yet been clarified convincingly is the relative importance of environmental circumstances on physical stature at different ages. This is irrelevant as long as anthropometric historians put the main emphasis on long-term trends of human stature. In order to determine whether

[9] *E. Horlings/J. Smits*, The Quality of Life in the Netherlands 1800-1913. Experiments in Measurement and Aggregation, in: *Komlos/Baten*, Biological, pp. 321-343, here 331.

there was a decline in height in the late 18th century, for example, it is relatively unimportant to know exactly whether this decline started in 1746 or 1748. Yet, short-term variations in height might provide further insights into the relationship between anthropometric and economic processes.[11]

Environmental factors during the first three years of life have undoubtedly the most important influence on *final* height. This influence is apparent, for instance, among Germans born during the hunger years of 1945-48, who remained significantly shorter than the preceding or subsequent generations.[12] Many examples reported below illustrate a close correlation between adult height and real wages at the time of birth.[13] Tanner reports in a recent essay that 1.3 cm (or 70%) of the ultimate 1.9 cm height difference between social classes in the United Kingdom was already present at age 2.[14] However, the question remains, how should we compare individuals across time who are *still growing*? That is, should we organize their height by year of birth or year of measurement, or a weighted average of both? The poorly nourished 19th-century Europeans were growing up to age 22 or 23, while 20th century populations and Americans and Australians of the 19th century reached their terminal height much earlier (around age 18). In the following paragraphs, I shall focus on the height of individuals still growing .

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[10] *J. Komlos/P. Coclanis*, On the "Puzzling" Cycle in the Biological Standard of Living: The Case of Antebellum Georgia, in: Explorations in Economic History 34, 1997, pp. 433-459.

[11] See also *U. Woitek*, Cycles in Heights. Unpublished manuscript Univ. Glasgow 1999, who finds a strong influence of the two years before measurement using spectral analysis.

[12] *H. Greil*, Age- and Sex-specifity of the Secular Trend in Height in East Germany, in: *Komlos/Baten*, Biological, pp. 483-496.

[13] Real wages and heights of male and female Bavarian convicts (organized by birth year) between the 1830s and 1870s are closely correlated, see *J. Baten/J. Murray*, Influences on Heights of Men and Women in Nineteenth Century Bavaria. Munich/Toledo mimeo. Figure downloadable under www.vwl.uni-muenchen.de/ls_komlos/joerg.html. Real wages are from *R. Gömmel*, Wachstum und Konjunktur der Nürnberger Wirtschaft (1815-1914). Bamberg 1978.

[14] *J.M. Tanner*, Introduction: Growth in Height as a Mirror of the Standard of Living, in: *J. Komlos* (ed.). Stature, Living Standards, and Economic Development: Essays in Anthropometric History. Chicago 1994, pp. 1-

Measured in 1947, seven to nine year old boys and girls born in 1938-40 were obviously malnourished **(Figures 1 and 2)**[15]. Measured again years later, this nutritional insult has left virtually no effect on their heights.[16] Catch-up growth during the following, much more favorable period of the 1950s and 1960s brought their height back to the growth trajectory that was mostly determined by the first two or three years of life. Those who were *born* in 1945-1947 remained shorter, however.

James Tanner recently suggested that "a low mean height at age 18 may be due to real stunting of growth and still be present at 25, or may be due simply to a delayed tempo and overcome by age 25."[17] He added furthermore that when environmental circumstances change, "growth is the first thing affected".[18] This points to a greater relative importance of the years preceding measurement. This notion is supported by the fact that the height series of the 7, 8, and 9-year-old children are closely correlated if they are organized by year before measurement, but nearly uncorrelated if organized by year of birth (except for the common trend). The same is true for Richard Steckel's slave manifest sample of black children.[19] The growth delay effect of the years around measurement dwarfs the birth year effect in those cases.

The same is true for a sample of 21,064 Bavarian conscripts of age 20. They were no exception to the fact that the relatively poorly nourished men of the 18th and 19th centuries grew until age 22 or 23: some of the conscripts were measured at age 21 and 22 again; a sample of 91 conscripts grew 1.4 cm between age 20 and 22, and 0.5

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[15] Data from *J.M. Tanner*, Foetus into Man: Physical Growth from Conception to Maturity. Cambridge 1990, p. 130.

[16] *Greil*, Age- and Sex-specifity.

[17] Ibid., p. 3.

[18] *Tanner*, Foetus.

cm of this growth took place between age 21 and 22. While average growth is overestimated with this sample, as only those soldiers were repeatedly measured that were initially unfit for service (for disease or height reasons), the values fit growth standards of that time relatively well.[20]

In a regression analysis of heights on real wages, a significant influence of the real wage level during the two years before measurement was found for Bavarian soldiers **(Tables 1 and 2)**. In contrast, regressing heights on real wages of the birth year (or an average of the first three years of life) yielded no significant results. Two alternative methods have been proposed to assign weights to different ages that might affect height: The YASSIS ('Yearly age- and sex specific increase in stature') and Coll's weights. Brinkman, Drukker and Slot developed the YASSIS weights arguing that the influence of environmental circumstances at a given age might be proportional to the share of growth accomplished at that age (see Table 1, column 1).[21] As infants grow fastest, the impact on later height is also large. Afterwards, the impact declines, rebounds during puberty, and declines again. Coll simplified this method by assigning weights that remained constant for a number of growth years (see Table 1, column 2).[22] Looking at the influence of real wages by weighing them with the YASSIS or Coll index did not produce statististical significance either.[23]

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[19] R. Steckel, The Health of American Slaves: New Evidence and Analysis. Paper given on SSHA conference in Chicago 1995. I thank Rick Steckel for letting me analyze his data, but I will not present them in table or graph before he firstly published using them.

[20] *E.Ph. Mackeprang*, De vaernepligtiges Legemshojde i Danmark. [Copenhagen] 1907-11.

[21] *H. Brinkman/J.W. Drukker/B. Slot*, Heights and Income: A New Method for the Estimation of Historical National Income Series, in: Explorations in Economic History 25 (1988), S. 227-264.

[22] *S. Coll*, The Relationship between Human Physical Stature and GDP (Some Experiments with European Time Series), in: *Komlos/Baten*, Biological, pp. 384-407.

[23] For other subsamples of Bavarian conscripts that were still growing, calculating composite indices based on the YASSIS curve always yielded lower R^2s in regressions on real wages, compared to regressions using real wages in the two years before measurement alone.

The correlation coefficient of the heights of the *still-growing* conscripts by year before measurement (YBM) with the *final* stature of adult convicts from the same region, but organized by birth cohorts is 0.59 **(Figure 3)**. Only the conscripts measured in 1835-39 (=birth cohort 1815-19) deviates from the expected trend - probably because they were born during the greatest famine of the century (1816/17), and this produced a permanent effect. If the famine cohort is omitted, the correlation coefficient rises to 0.79.

The more dependent a regional population was on buying food in the market, the higher was the elasticity of their heights with respect to real wages. The most obvious example is the weaving district of Stadtsteinach in Northeastern Bavaria **(Figure 4)**, but the conscripts born in the other early industrial districts also show a significant relationship **(Figure 5)**.[24]

Hence, the following rule-of-thumb seems appropriate: if the analysis pertains to youth, then the economic and environmental conditions during the year immediately preceding the year of measurement should be considered, while for adult heights one should use explanatory variables at time after birth. One possible explanation is that for infants the immediate impact of exogenous factors on growth may very well be substantial. Over the years, however, a certain amount of catch-up growth may occur with the result that the anthropometric impact of insults during the early years might well be dwarfed by strong but temporary growth retardations or increases, and this temporary effect is measured in the heights of still-growing-conscripts. Additional catch-up growth might occur later, leading to a final stature mainly determined by the

[24] See also *Woitek*, Cycles.

first years of life. Hence, in the long run as far as final adult heights are concerned, the nutritional status of the infant might have mattered the most.

3. The height-real wage relationship in the 18th century: Austria, Bavaria, Sweden, UK

Komlos was the first to describe a strong downward trend of heights in the late 18th century.[25] Comparing his height estimates for the three western provinces of the Habsburg Empire to the purchasing power of daily wages reported by Sandgruber, a common movement of the two series between the 1750s and the 1790s is quite apparent **(Figure 6)**.[26] During the two decades before mid-century the series do not move together, however. In the 1730s, real wages in Austria seem to have reached their 18th century peak, while heights were increasing and reached their maximum a decade later. The downward deviation of real wages in the 1740s is known to be caused by the hunger years of 1740/41 that seems to have left no permanent mark on adult heights. The same is true for Bavaria **(Figure 7)**. In this figure, heights by birth cohort and real wages are given by five year averages.[27] In Sweden, the climatically favorable 1730s stand out even stronger in terms of real wages **(Figure 8)**. After this decade, real wages declined mildly or stagnated until about 1800, while heights started to recover somewhat in the very last decades- similarly to the Bavarian and Austrian case.[28]

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[25] *J. Komlos*, Nutrition and Economic Development in the Eighteenth-Century Habsburg Monarchy: An Anthropometric History. Princeton 1989.

[26] *R. Sandgruber*, Die Anfänge der Konsumgesellschaft: Konsumgüterverbrauch, Lebensstandard und Alltagskultur in Österreich im 18. und 19. Jahrhundert. München 1982.

[27] *Baten*, Ernährung.

[28] *M. Heintel/L. Sandberg/R. Steckel*, Swedish Historical Heights Revisited: New Estimation techniques and Results, in: *Komlos/Baten*, Biological, pp. 449-458. Swedish prices are from *L. Joerberg*, A History of Prices in

A similar recovery did not take place in England **(Figure 9)**.[29] Perhaps due to the Napoleonic wars, English heights declined until the 1800s. This is confirmed by the heights of boys of the Marine society in London **(Figure 10)**. [30] In sum, real wages and heights in the 18th century are characterised by very similar general trends.

4. Heights and real wages in the 19th century: UK, US, Sweden, Bavaria, France, Netherlands

Between the 1800s and 1820s, both the Marine society and military data display a strong recovery.[31] Mokyr and O'Grada's estimates for the East India company`s army confirm this recovery, while Riggs' estimates based on a sample of Scottish convicts are less optimistic for this regard.[32]

That the trend of heights and real wages diverged after the 1820s in the United Kingdom and the U.S., is known as the early industrial growth puzzle (**Figure 11)**.[33] A key to the understanding of this puzzle might be that the heights of rural population declined the most, while those of urban workers the least, and that the real price of nutrients increased. In the UK, the height of female rural criminals declined about 1.5 cm between the 1820s and the late 1840s, while the urban ones declined only about 1

Sweden 1732-1914, vol. 2. Lund 1972. The districts of Vaestermanland and Vaesternorrland were excluded, because they followed a completely different path, compared with the other 11 districts, so that I would regard them as outliers. Otherwise, Swedish real wages would stagnate, not decline.

[29] According to the estimate in Komlos, Secular. For a contrary view see Roderick Floud/Bernard Harris, "Health, Height and Welfare: Britain, 1700-1980," in: *Steckel/Floud*, Health, pp. 91-126. Real wages are from *E.A. Wrigley/R.S. Schofield*, The Population History of England 1541-1871. Cambridge 1981.

[30] *M. Heintel/J. Baten*, Smallpox and Nutritional Status in England, 1770-1873. On the Difficulties of Estimating Historical Heights, in: Economic History Review 51, 2, 1998, pp. 360-371; *J. Komlos*, Shrinking, p. 781.

[31] *Heintel/Baten*, Smallpox.

[32] *J. Mokyr/C. O'Grada*, Height and Health in the United Kingdom 1815-1860: Evidence from the East India Company Army, in: Explorations in Economic History 33, 1996, pp. 141-168; *P. Riggs*, The Standard of Living in Scotland, 1800-1850, in: *Komlos*, Stature, pp. 60-75.

[33] *Komlos*, Shrinking.

cm.[34] Similarly, the height of Scottish female prisoners declined more in the rural than in the urban areas.[36]

There are a number of additional potential reasons for this divergence. In the U.S. case Komlos argued that the two most important reasons probably were: the increasing relative price of nutrients and market integration. The U.S. was gradually developing from a frontier economy (with extremely high protein supply) to a modern industrialized society. Other potential explanations, such as increases in the inequality of income, or high income variability effects also affected the other European countries, for which we find positive height-real wage correlations in the 1830s and 1840s.[38]

A factor that caused pressure on the UK and U.S. economies was the strong population growth during the early 19th century.[39] But how could population growth affect people's nutritional status, if real wages were not declining? I have argued elsewhere that in the British case, the increasing relative price of protein might have played a role, as it was more difficult to nourish this already densely settled and rapidly urbanizing country with enough animal protein, while starches were easier and cheaper

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[34] *P. Johnson/S. Nicholas*, Health and Welfare of Women in the United Kingdom, in: Steckel/Floud, Health, pp. 201-249, here p. 221; for the most recent survey - but contrary arguments - on English height studies, see *Floud/Harris*, Health.

[36] *Riggs*, Standard. In contrast, Floud, Wachter and Gregory argued that urban heights declined more than rural ones. *R. Floud/K. Wachter/A. Gregory*, Height, Health and History. Nutritional Status in the United Kingdom, 1750-1980. Cambridge 1990, pp. 205-7. However, their result might be due to their defininition: "urban" were all inhabitant of large regions around London, Manchester, Newcastle and in South Wales, including many rural inhabitants of the English North, the area around London, and the Walisian South. On the other hand, a lot of smaller towns outside of these areas were counted as "rural", see ibid., p. 201. It is likely that the inhabitants of areas near towns declined most between 1820 and 1840, the period of rapid urbanization, because farmers in these areas near towns sold more and more milk and meat on the urban markets. In contrast, day-laborers of these regions, who previously consumed milk at negligible prices, might have had to buy food in the market subsequently, competing with urban dwellers of higher purchasing power.

[38] *Komlos*, Shrinking. On income inequality and real wage variability in Bavaria, sor example, see *Baten*, Ernährung, pp. 105-109.

[39] The English population grew by 1.4% per year during the early 19th century, the Prussian only by 1.1% and the

to import.[40] Horrell found a shift in lower class budgets during this time away from animal proteins towards starches and industrial goods: Household budgets of 1840-54 contained 19% more expenditures on starches and grain (compared to 1830-39), but 8% less milk, butter and cheese, 19% less for meat, fish, eggs and fat.[41]

Aside from these two exceptional (Anglo-Saxon) cases, the general pattern of height and real wage trends in the rest of Europe is similar to one another. In Sweden, real wages and heights improved considerably between 1800 and the nutritionally favorable 1820s. Afterwards real wages declined modestly and heights stagnated until mid-century, starting an upward trend thereafter **(Figure 12)**. Essentially the same pattern was found for Bavarian female convicts: real wages at the year of birth is positively correlated with heights.[42]

Dutch heights also increased until the late 1820s and declined considerably thereafter **(Figure 13)**.[43] Real wages increased in the Netherlands until the early 1820s; afterwards there was no permanent improvement, until after the 1860s. If one recalculates real wages by giving greater weight to foods rich in animal protein, the result would be a decline in "protein weighted" real wages from the 1820s to 1850s. The consumption of bread and potatoes declined much less than the intake of protein-rich meat, cheese and milk.[44]

French population by 0.45%. The population of Saxony was growing faster. See *Baten*, Ernährung, p. 45.

[40] *Baten*, Ernährung, p. 108-110. Relative prices are calculated from *A. Jacobs/H. Richter*, Die Grosshandelspreise in Deutschland von 1792 bis 1934, in: Sonderhefte des Instituts für Konjunkturforschung, 37, ed. by E. Wagemann. [Berlin] 1935. On England, see *B.R. Mitchell*, British Historical Statistics. London 1988.

[41] *S. Horrell*, Home Demand and British Industrialization, in: Journal of Economic History 56, 3, 1996, pp. 561-604, here p. 580.

[42] *Baten/Murray*, Influences. In addition, we have seen above, that the male conscript sample responded sensitively to real wage changes, especially in the more industrial districts.

[43] J.*W. Drukker/V. Tassenaar*, Paradoxes of Modernisation and Material Well-Being in the Netherlands during the Nineteenth Century, in: *Steckel/Floud* (1997) pp. 331-378.

[44] *Horlings/Smits*, Quality, p. 331.

If one considers Dutch real wages and heights on an annual basis, the elasticity of height at age 19 becomes quite clear **(Figure 14)**.[45] Especially during the crises and recoveries around mid-century, heights reacted very sensitively to real wage changes. France experienced a similar stability of real wages - averaged by five-year-groups - as the Netherlands did.[46] If one examines the height and real wage relationship on an annual basis, a short term decline around 1846/47 and 1853/54 is visible in the series, causing a significant correlation **(Figure 15)**.

5. Heights and infant mortality as a proxy for disease environment

The disease environment also influences physical stature.[47] A frequently used proxy for it is the infant mortality rate. Using the incidence of individual diseases would be problematical, because it is difficult to weigh the importance of one disease against another, and the classification of disease in the 19th century is unsystematic.[48] To be sure, infant mortality itself has drawbacks as a proxy for the disease environment, insofar as it is also influenced by nutritional intake. Future research should explore methods of orthogonalization, so that an index, independent of food intake, could be developed for the severity of the disease environment.

Infant mortality had little influence on heights according to the six multiple regressions reported in Table 3. Only in the Dutch case is its coefficient close to

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[45] Dutch real wages are from A. Vermaas, Wages, Salaries and Income Inequality in the Netherlands 1850-1913 (forthcoming), cited after *Horlings/Smits*, Quality, p. 342.

[46] *D. Weir*, Economic Welfare and Physical Well-Being in France, 1750-1990, in: *Steckel/Floud*, Health, pp. 161-200. Real wages are from *J.G. Williamson*, The Evolution of Global Labor Markets since 1830: Background Evidence and Hypotheses, in: Explorations in Economic History 32, 1995, pp. 141-196.

[47] For arguments, why this factor also alone does not explain the "Early Industrial Growth Puzzle", see Komlos, Shrinking. For example, the growth of large industrial cities with problematic hygienic conditions should also have had an influence on heights between the 1800s and 1820s, but during this period heights were increasing.

[48] R. Spree, Der Rückzug des Todes. Der epidemiologische Übergang in Deutschland während des 19. und 20. Jahrhunderts, in: Historical Social Research 23-1/2 (1998), pp. 4-43.

statistical significance (p-value=0.11) and has the expected sign. For France, the real wage variable has a significant influence, but not the disease proxy. The Bavarian real wage coefficient is also significant, and it makes no difference whether infant mortality is included or not.[49]

6. Conclusion

The real wage - height relationship is apparent in most of the cases we considered, with the exception of the U.S. and Great Britain between 1820 and 1840. The "Early Industrial Growth Puzzle" of Britain and the U.S. appears to be the exception, rather than the rule. The only other significant exception deserving additional attention is the 1730s, which witnessed favorable real wages in several countries, but had less of a positive response in terms of heights. In addition, Dutch real wages displayed no significant trend, while heights declined until mid-century. This might be explained by a shift from protein-rich foods to starches.

The methodological section of this paper was devoted to the question whether the influence of real wages on heights of individuals still growing was stronger when the year of measurement was the basis of comparison or the year of birth. The results were based on the analysis in the anthropological literature and on regression analysis of the height-real wage relationship for both ages (or a weighted average of all ages). I conclude that the years before measurement had an influence on heights, if the measured individuals were still growing. If they were measured after reaching their final height, then the environmental circumstances of the first years after birth had the stronger influence.

[49] I also tested the height and real wage series for trends and for unit roots, using the Augmented Dickey Fuller test (ADF). The results are available on http://www.vwl.uni-muenchen.de/ls_komlos/joerg.html.

Finally, the influence of real wages was contrasted with a possible additional influence of the disease environment, proxied by infant mortality rates. This influence was not found in the French or Bavarian cases of the 19th century, only in the Netherlands is there some evidence of a significant influence. The reason for this might be that the Netherlands was the most urbanized country of Europe, and therefore quite vulnerable to disease encounters. In conclusion, the generalization might be appropriate that the correlation between height and real wages in the 18th and 19th centuries was stronger, the less developed the economy was. Further anthropometric research in this direction should reveal more such relationships.

Table 1: Weights given to environmental influence on adult height

Age	YASSIS Weight	Coll Weight
01	15.4	1.00
02	9.2	1.00
03	7.5	1.00
04	6.7	1.00
05	5.8	1.00
06	5.0	0.45
07	5.0	0.45
08	4.2	0.45
09	3.3	0.45
10	3.3	0.45
11	3.3	0.45
12	4.2	0.45
13	4.2	0.45
14	4.2	0.50
15	5.0	0.50
16	5.0	0.50
17	4.2	0.50
18	2.5	0.50
19	0.8	0.50
20	0.8	0.50
Sum	100	12.1

Notes:
YASSIS: 'yearly age- and sex-specific increase in stature'. The weights of environmental influence according to the average growth at all ages as proposed by *Brinkman/Drukker/Slot*, Height.
Coll: see *Coll*, Human Stature.

Table 2: Four weighted least square regressions of height at age 20 (=dependent variable) on real wages in Bavaria, different weighing procedures (N=30 years)

Regr. No.	1	2	3	4
Age	19/20	1-20	1-20	1-3
method	YBM	YASSIS	Coll	BY
Real wage	0.03*	0.00	0.00	0.00
R square	0.35	0.00	0.00	0.00
Durbin-Watson	1.65	1.58	1.59	1.56

Notes and abbreviations: * Indicates significance at the 1% level. None of the series contains a significant time trend (0.01-level).
YBM: real wages are those of the two years before measurement. One outlier was excluded (1843), that was more than 2 s.d. from the mean, otherwise the R square would have been 0.26, significance levels and coefficients remain unchanged.
YASSIS and Coll: see Table 1 for the relevant weights used to weigh the real wages during the life course of the recruits.
BY: real wages are those of the first three years of life.

Table 3: Six Regressions of height on infant mortality and real wage

	1	2	3	4	5	6
	NL	FRA	BAV	NL	FRA	BAV
Constant	163.1*	162.2*	164.8*	163.6*	162.3*	164.4*
Infant mortality				-0.45	-0.08	0.13
Real wage	4.77*	5.41*	1.90*	4.73*	5.45*	1.85*
Lagged dependent var.	0.89*			0.70*		
Log Likelihood	-164.0			-150.6		
R square		0.78+	0.14		0.78+	0.14
Durbin-Watson		1.30+	1.87		1.36+	1.84
N	63	39	29	41	39	29

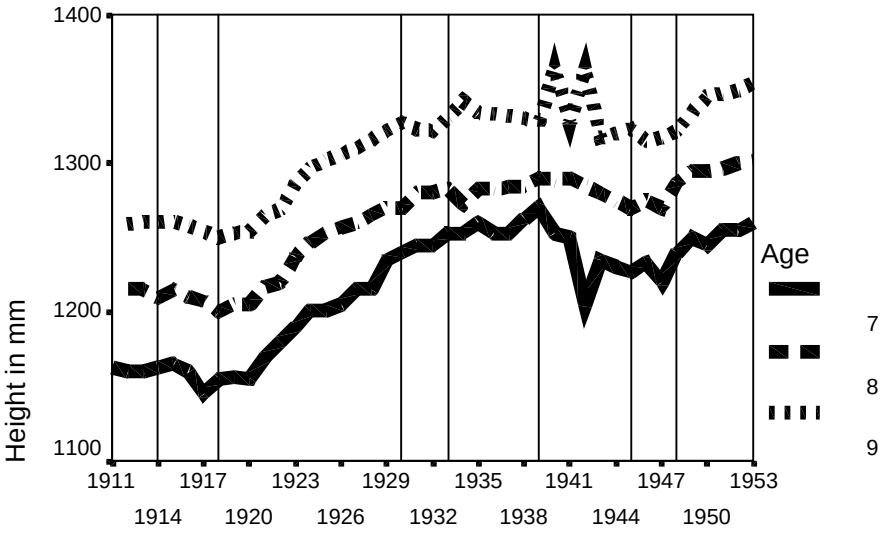
* Indicates statistical significance at the 10% level.

+ Invalid due to unit root, but cointegration analysis (see tests on www.vwl.uni-muenchen.de/ls_komlos/joerg.html) confirmed consistent estimate.

Cofficients (except constants) are multiplied by 100 for better readability.

Sources: See text. Infant mortality rates are from *B.R. Mitchell*, International Historical Statistics: Europe 1750-1988. New York, 3rd ed. 1993; and for Bavaria: Beiträge zur Statistik des Königreichs Bayern. München (various years).

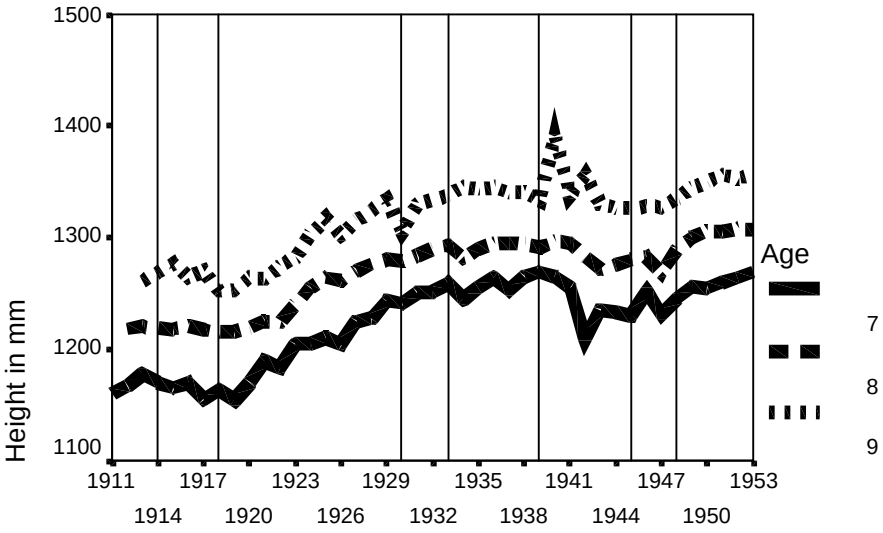
Figure 1: Height of Stuttgart girls



Year of measurement

Source: Tanner, Foetus, p. 130.

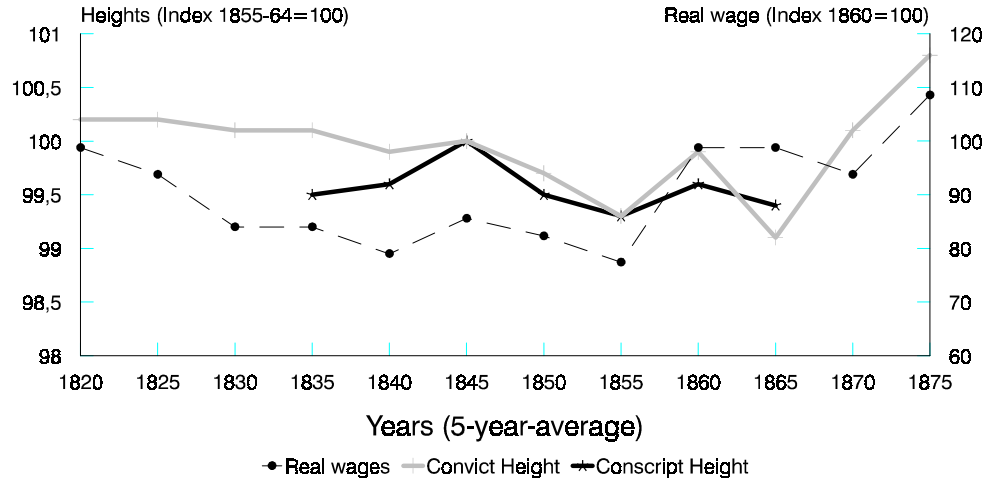
Figure 2: Height of Stuttgart boys



Year of measurement

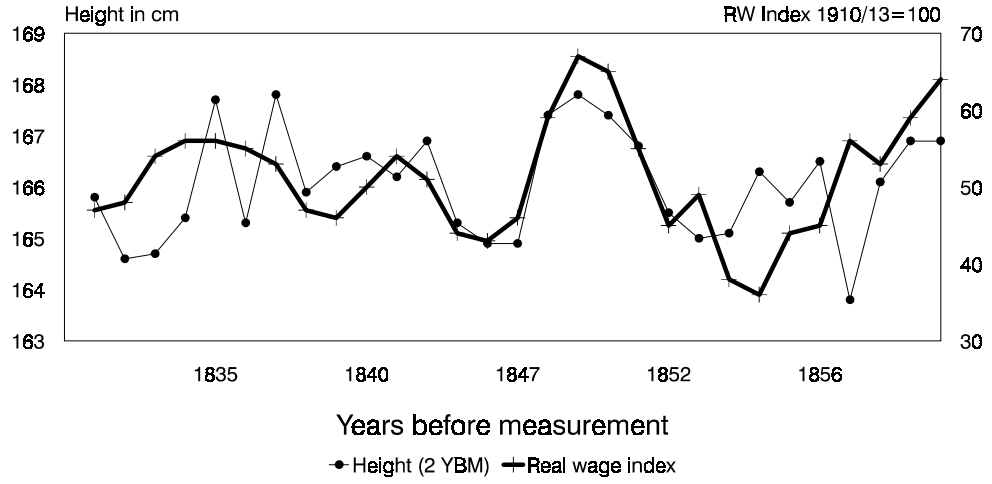
Source: Tanner, Foetus, p. 130

Figure 3: Real wages and male heights (Convicts and Conscripts) in Bavaria



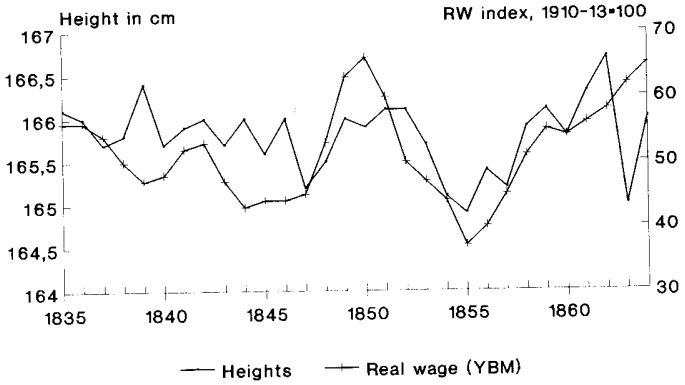
Source: Gömmel, Wachstum; Baten, Ernährung. Conscripts by year before measuremet (adolescents), convicts by BY

Figure 4: Heights and real wages in the weaving region of Bavaria, 19th century



c:\k\z19\gj_bambe.cht
Source: StA Bamberg, CS-L. Stadtsteinach
Data on 1844,45,61,62 are not avalaible.

Figure 5: Heights and real wages, other indsutrial Bavarian districts



Sources: *Baten*, Ernährung; *Gömmel*, Wachstum. Weaving district excluded. Height refers to two years before measurement. 1842/43/69/70 miss.

III. The height-real wage relationship in the 18th century: Austria, Bavaria, Sweden, UK

Figure 6: Heights and real wages in Austria

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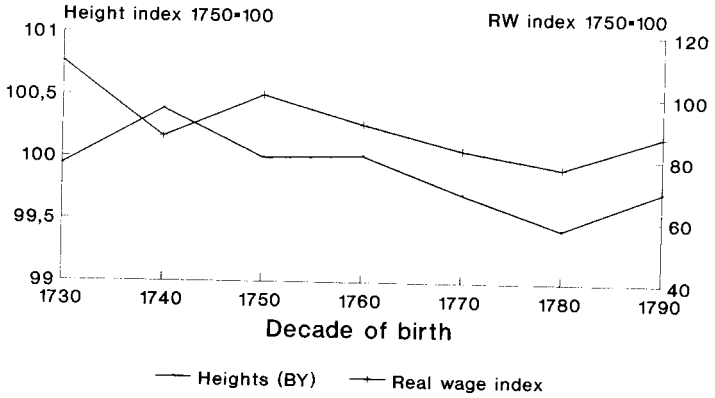

Sources: *Komlos*, Nutrition; *Sandgruber*, Anfänge (wage / (70 percent bread price + 30 percent meat price
Height refers to birth decades (adults).

Fig. 7: Heights in Bavaria and grain/potato production per capita

Source: Baten, Ernaehrung. Height refers to birth decades

Figure 8: Heights and real wages in Sweden, 18th century

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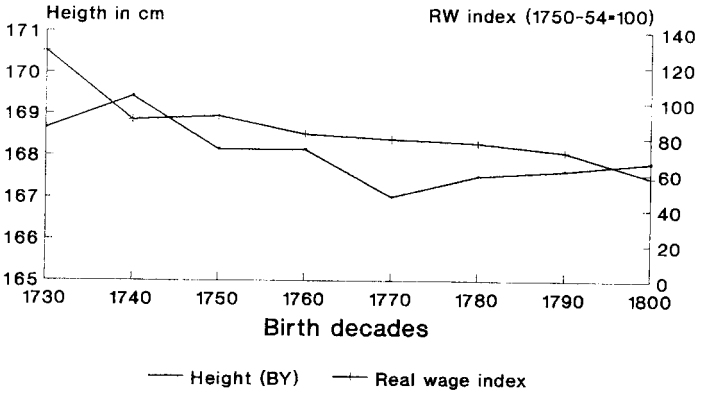
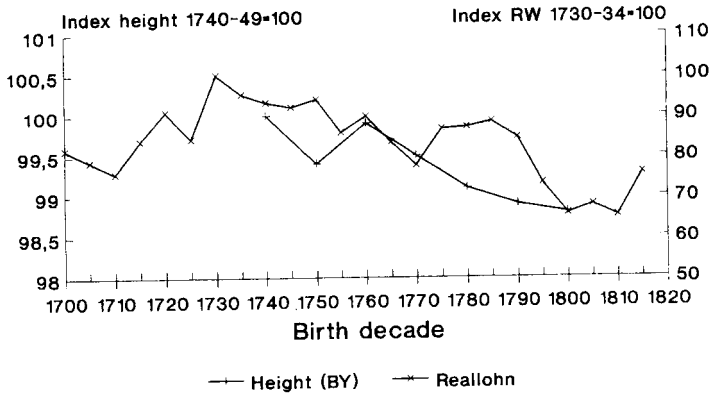


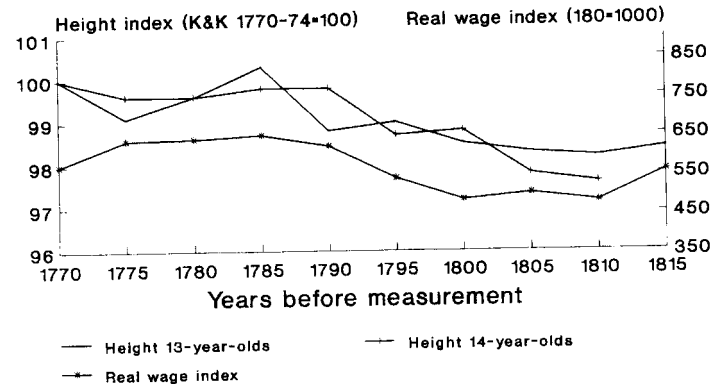
Sources: *Joerberg*, History, p. 188; *Heintel/Sandberg/Steckel*, Swedish. Height refers to birth decade (adults).

Figure 9: Heights and real wages in England, 18th century



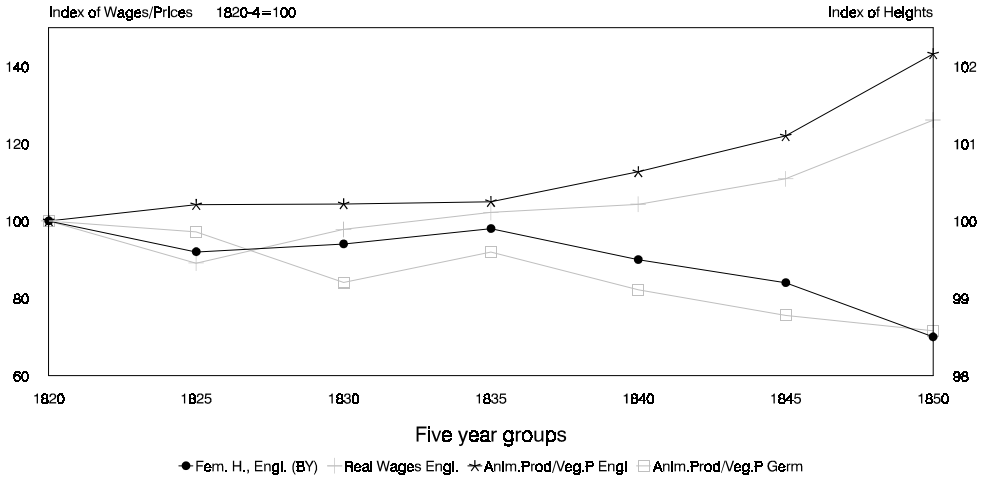
Sources: *Wrigley/Schofield*, Population; *Komlos*, Secular. Height refers to birth year (mainly adults).

Figure 10: Heights of London boys (Marine society) and real wages



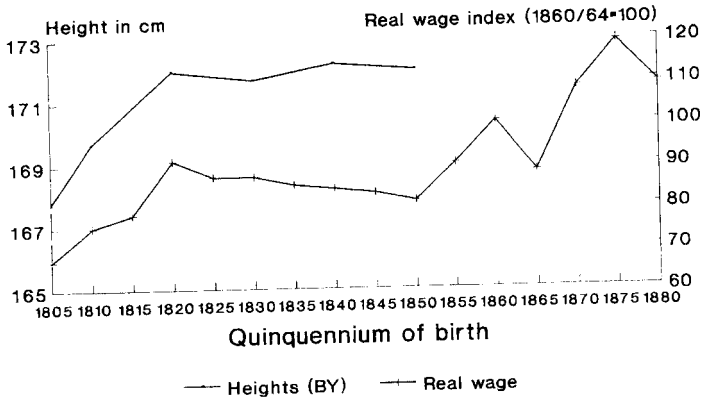
Sources: *Heintel/Baten*, Smallpox; *Wrigley/Schofield*, Population. Height refers to years before measurement (boys).

Fig. 11: English heights, real wages, and relative prices for animal products



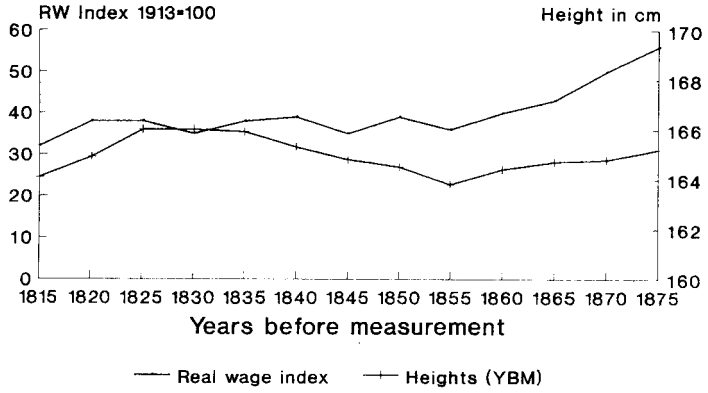
Source: P. Johnson/S. Nicholas (1995), A. Jacobs/ H. Richter (1935), B.R. Mitchell (1988)

Figure 12: Heights and real wages in Sweden, 19th century



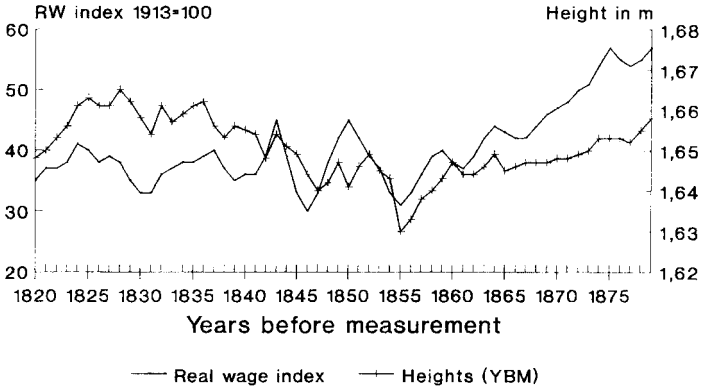
[illegible] Swedish: Joerberg. History. Height refers to birth years (mainly adults).

Figure 13: Dutch heights and real wages, 19th century



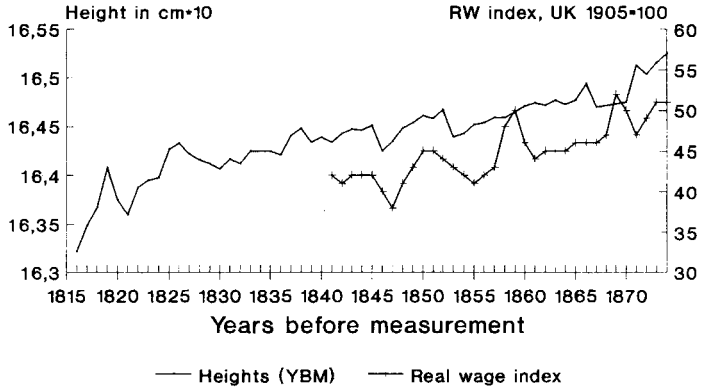
Sources: *Vermaas*, Wages; *Drukker/Tassenaar*, Paradoxes. Height refers to two years before measurement (adolescents).

Figure 14: Dutch heights and real wages, 19th century



Source: see figure 13. Height refers to two years measurement (adolescents).

Figure 15: Heights and real wages in France, 19th century



Sources: *Weir*, Economic; *Williamson*, Evolution. Height refers to year before measurement (adolescents).

V. Heights and infant mortality as a proxy for disease environment

The disease environment also influences physical stature [45]. A frequently used proxy for it is the