

Health, Urbanization, and Economic Growth

Julianne Treme^a, Lee A. Craig^b

^a *Department of Economics, Wake Forest University, Winston-Salem, NC 27106
United States*

^b *Department of Economics, North Carolina State University, Raleigh, NC 27695-
8110, United States*

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Abstract

The move towards an industrialized society has been described in terms of an unambiguous rise in living standards as measured, for example, by gross domestic product. However, the study of living standards is no longer limited to GDP. Biological indicators, such as stature, have emerged as important alternatives to measure the well being of a society. The industrial strides and public health measures taken in conjunction with fluctuations in stature make the nineteenth century a key period of study not only for countries with long histories, but also newly established ones. While previous research focuses on country-level data to document changes in height, no study has made an empirical statement on the global significance of the determinants of height. We construct a global water supply variable, which is the first of its kind, and use it to test whether securing healthy water supplies significantly affected height. Death rates, GDP, urbanization, water supply quality, coal production and railway mileage were used to study the evolution of height in a cross-section of countries from 1800 to 1920. The results indicate water supply quality positively impacted height, while urbanization and GDP effects varied by country. In fact, GDP and height were negatively correlated in some cases. Overall, it seems height broadly affected and reflected a common set of factors and the global coefficients offer a broader picture of the determinants of height over the period 1800-1920.

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E-mail addresses: tremej@wfu.edu (J. Treme), lee_craig@ncsu.edu (L.A. Craig)

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Introduction

The nineteenth century was marked by the spread of urbanization and industrialization. Economies wholly dependent on agricultural output transformed into economies reliant on heavy machinery and transportation improvements. The move towards an industrialized society has been described in terms of an unambiguous rise in living standards as measured, for example, by gross domestic product. However, the study of living standards is no longer limited to GDP. Biological indicators, such as stature, have emerged as important alternatives to measure the well being of a society.

Several country-level studies have identified height puzzles, or periods of simultaneous economic growth and human stature declines. These include Sweden, the Habsburg Monarchy, France, and Bavaria in the eighteenth century and the Netherlands, United Kingdom, and United States in the nineteenth century (Haines et al 2003; Floud and Harris 1997; Drukker and Tassenaar 1997). The divergence between economic and biological indicators suggests that drawing conclusions from income observations yields potentially misleading conclusions if the change in environment is not taken into account. If the biological costs are greater than the benefits conferred by higher incomes, then a rise in income cannot be interpreted as a sign that on average people were unambiguously better off.

While both GDP and stature allow researchers to describe economies in terms of consumption and production decisions, stature does so in a slightly different manner: through the consumption of nutrients and the physical costs associated with the

production of goods. The consumption of nutrients – net of those exhausted during work or while fighting disease – determines whether *homo-sapien* populations achieve their genetic height potential. Occupation choice determines the difficulty of labor, number of hours, and working conditions imposed on the body. Physically challenging occupations face increased demands on nutrition entering the body for maintenance, leaving little left over for growth. Similarly, diseases can be spread more easily as people begin to work closer together, placing further demands on the body.

Net nutritional status is the difference between caloric inputs and caloric demands of work, body maintenance, and disease. A positive net nutritional status stimulates growth while a negative net nutritional status will retard growth, *ceteris paribus*, of course.¹ Thus, as Cuff (2005) explains, adult stature can be viewed as a “cumulative indicator of net nutritional status over the growth years” (p. 10). Changes in nutrition, working conditions, and disease environment can all influence net nutritional status.

In addition, disease environment reflects public health measures, urbanization, and economic expansion. Nineteenth century medical knowledge was limited, and even after discoveries were made, significant lags preceded their adoption into everyday life. Heights also declined because of urbanization (see below), as populations were living closer together and the possibility of spreading disease was higher, especially in the absence of effective health measures. Fogel (1986) finds urbanization explains approximately 20 percent of the United States stature decline for birth cohorts from 1830 to 1860. Economic expansion encouraged transportation improvements and the

¹ There is a biological maximum to the mean stature of a population, and for those populations enjoying a surplus of nutrients, further consumption would merely lead to obesity.

development of transportation alternatives would have spread disease to locations previously isolated from such sickness. For instance, the first epidemic appearance of cholera in the United States in the 1830s was spread through trade routes (Steckel 1995). The fear of cholera led many European nations to favor quarantines as a way to combat the epidemic. Scandinavia was particularly committed to the idea. They reasoned that the southern and more urbanized areas of Europe were susceptible to cholera from all sides and that their peninsular topography made it possible to build a barrier to the disease by imposing quarantines on their populations (Baldwin 1999).² These measures decreased real economic activity.

Haines (2003) examined the fall in stature in the United States, England, and Netherlands in the nineteenth century and argued that urbanization, (lack of) public health measures, transportation, and fluctuation of food prices contributed to the biological downturn. Steckel (2001) has studied long-term global height developments with an emphasis on the role of industrialization in shaping human stature in the nineteenth century. The industrial strides and public health measures taken in conjunction with stature fluctuations make the nineteenth century a key period of study not only for countries with long-standing histories, but also newly established ones. Thus as Deaton(2006) notes in his review of Fogel (2004), there is a great debate between those (like Fogel) who emphasize economic growth as the key to living standards, and those (like Deaton) who emphasize public health measures. Below, we employ both economic and health variables, as well as measures of urbanization, to study the evolution of height in a cross-section of countries in the nineteenth century.

² Quarantines would not have been feasible in the United Kingdom, given its proximity and connections to Europe (Baldwin 1999)

Height and GDP

The countries used in the analysis are the United States, United Kingdom, Netherlands, France, Sweden, Belgium, Denmark, and Germany, and we employ decadal data ranging from 1800 to 1920. Unfortunately, the countries were selected based on the availability of data, although they do represent a cross section of the early-developing countries. One goal of this essay is to move beyond the country-specific analysis of height and take a global, or at least an Atlantic, perspective to determine which economic and non-economic variables may contribute to the variation of stature in different parts of the world. Fluctuations in variables such as height, urbanization, and per capita GDP provide an opportunity to examine global biological coefficients in the nineteenth century.

Figure 1 shows how average height changed in the nineteenth century for the Netherlands, United Kingdom, and United States. The figure shows there is not a unidirectional, upward trend in stature in the nineteenth century. Indeed, the behavior of height is cyclical. Human stature rose early in the century, fell mid-century, and began to rise again at the end of the century in the Netherlands and the United States, and the general pattern is evident in the United Kingdom with additional fluctuations toward the end of the century. The magnitude of the downturns in stature was not uniform across countries. The highest fluctuation occurred in the United Kingdom between 1840 and 1850 with a downturn of almost 3.5 centimeters, or 1.38 inches. This was followed by the United States with a 1.7-centimeter downturn, or 0.67 of an inch, between 1870 and 1880, and the Netherlands with a downturn of 1.2 centimeters or 0.47 of an inch, between 1830 and 1840. Fluctuations in height were also observed in Denmark, Sweden, and

Belgium in the nineteenth century and are illustrated in Figure 2. Figure 3 shows France is unique in that stature did follow an unambiguous, upward trend throughout the nineteenth century.³ (All of the height data measurements are reported in Appendix A.)⁴

One question that emerges from the growth literature is: Is it necessary to examine height? If GDP and height move together, then it is possible to argue that GDP is sufficient to determine living standards in the nineteenth century. Figures 4 through 10 show height and GDP trends in the nineteenth century for Sweden, United States, United Kingdom, the Netherlands, France, Denmark, and Belgium. With the exception of France, each figure shows the divergence of height and income measures at some point(s) in the century. In other words, the physical or biological costs associated with GDP increases overshadow its physical benefits. Therefore evidence exists to support the study of height as it pertains to living standards in this time period.

Determinants of Stature

As stature and GDP were changing in the nineteenth century, societies were evolving in other areas as well. Urbanization was rapidly rising, death rates were falling, railways were being built, industrialization was taking off, and public health was beginning to emerge as an important concern in society. We employ regression analysis to determine the effects each variable has on stature in the nineteenth and early twentieth centuries and test whether specific improvements in public health, such as improvements in public water supplies, were significant in helping to overcome the negative externalities associated with urbanization and industrialization.

³ A height puzzle was observed in France in the eighteenth century.

⁴ Height data were only available for five decades in Germany and the figures are shown in Appendix A.

The data set has both a spatial and temporal dimension. The spatial dimension refers to the cross-section of countries and the temporal dimension refers to the decadal observations of stature and its determinants over the 1800-1920 range of time. This time-series, cross-sectional data set has ten countries and twelve decades. Limitations in data availability prevented the construction of a data set with equal time coverage from country to country. Therefore the resulting data set represents an unbalanced panel.

The regression model employs differential intercepts and slopes varying according to country. This is achieved by including country dummy variables and their interactions with the time-varying covariates, specifically urbanization and GDP. For example, urbanization in the United Kingdom is the interaction of urbanization and a dummy variable equal to 1 if the country is the United Kingdom. The purpose of defining the variables in this way is to determine whether urbanization (GDP) has a unique impact on stature in varying countries. Fixed effects are also included to control for the common variations in stature. Equation 1 shows intercepts and urbanization and GDP slopes that vary with the country.

$$\text{Height}_{it} = \beta_1 + \beta_2 \text{DeathRate}_{it} + \beta_3 \text{Urbanization}_{it} + \beta_4 \text{GDP}_{it} + \beta_5 \text{Transportation}_{it} + \beta_6 \text{Water}_{it} + \beta_7 (\text{GDP}_{it} * \gamma_i) + \beta_8 (\text{Urbanization}_{it} * \gamma_i) + \gamma_i + \varphi_t + \beta_9 \text{CoalProduction}_{it} + e_{it} \quad (\text{Equation 1})$$

These control variables are used in all regressions.

γ_i are country dummies which take into account country-specific framework conditions that might affect height.

φ_t are decadal time dummies which take into account shocks that are common to several countries.

The variables (for country i and time t) are defined as follows:

- Height is the average or median height of a population.
- Death Rate is the crude death rate per thousand of a population.
- Urbanization is the percentage of the population living in urban areas.
- GDP is the gross domestic product.
- Transportation is the length of railway line open (in kilometers).
- Water is the decade in which healthy public water supplies were secured in each country.
- Coal Production is measured by the output of coal (in metric tons) for each country.

The coefficient on death rates is expected to be negative. Higher death rates are associated with poor living conditions, diet, and access to medical care. Each factor affects net nutritional status negatively and therefore an increase in death rates would be expected to lead to a decrease in stature. Haines et al. (2003) found a statistically significant negative relationship between crude death rates and stature in the antebellum United States. Floud (1994) found a negative and statistically significant relationship between crude death rates and adult male height in eight European countries over the years 1880 to 1970.

The coefficient on urbanization would be expected to be negative. Urban areas were known for their crowding and deficient public health measures. The lack of public health measures for most of the century would have exacerbated the problem of crowding

and vice versa. In an isolated population, unhealthy living habits affect only a small portion of the population. In urban areas, however, when forced to live and work in close quarters, poor personal hygiene would no longer be contained to the individual. Given the state of medical technology in the nineteenth century, the situation could easily become a dangerous one in terms of health as net nutritional status is compromised and fewer nutrients are available for growth. The urbanization interaction variable will test the hypothesis that urbanization had a different impact on stature in varying countries.

At the turn of the nineteenth century, urbanization rates ranged from 6 to 37 percent and were lowest in the United States and Sweden and highest in the Netherlands and the United Kingdom.⁵ By the twentieth century, the United States had experienced an urbanization increase to almost 40 percent while Sweden's remained under 25 percent. The urbanization effect in Sweden would be expected to have a less severe impact on stature than the remaining countries in the sample. Urbanization in the United States and the United Kingdom would be expected to have a larger, negative impact on stature because of the rapid rise in urbanization in the United States and the magnitude of the percentage of urban population in the United Kingdom. It is not clear whether the interaction term with the Netherlands will be significant. On the one hand, their initial urbanization rates were quite high, but on the other, the rates did not keep pace with the United Kingdom or the other countries in the sample.

GDP per capita is expected to have a positive effect on stature. Since food consumption accounted for a large portion of total income of the laboring class, income can be directly linked to nutritional status and hence stature (Komlos 1994). Higher-income individuals have the ability to purchase higher quality goods, such as housing,

⁵ See Appendix A for urbanization data by country.

protein-rich food, and medical care and the goods can be seen as being positively correlated with health and therefore stature (Auster et al. 1969; Fogel 2004). However, income decisions do not always lead to healthy choices. Indeed it appears higher incomes were spent, at least partly, on alcohol, tobacco, sugar, and in general less healthy diets (Clark et al. 1995). If income was spent primarily on goods negatively related to their health, the sign on GDP should be negative. Furthermore, Steckel (1995) notes improvements in stature stemming from increases in income are not unlimited. Once growth is complete, a rise in income will not lead to additional stature improvements. If a high degree of income inequality was present in societies, then the coefficient on GDP would not be expected to be significant because incomes were rising only for people who had already reached their genetic potential. The GDP interaction variable will test the hypothesis that GDP had a different impact on stature in varying countries. Following Clark et al. (1995), the interaction variable with the United Kingdom would be expected to yield a lower GDP effect on height when compared to other countries, and because the U.K. and the U.S. economies were closely integrated, the same could be true of the United States.

There is not a clear expectation of the sign on transportation. Transportation is measured by the length of railway line, in kilometers, for each country. The coefficient could be positive if the expansion of transportation opportunities allowed larger segments of the population to enjoy a more varied diet. However, Komlos (1994) and Craig and Weiss (1998) suggest transportation improvements came with a cost, as food was less dense in nutrients on arrival. In addition, the development of the railroad could have spread disease to locations previously isolated from such sickness.

To represent the recognition of the low quality of water provisions and its danger to public health, a dummy variable was constructed to determine when healthy water supplies were secured in each country by identifying the decades in which the application of water filtration techniques and the evolution of water systems would have been most likely to have a positive and significant effect on height in urban areas.⁶ In other words, the dummy variable will take on a value of 1 beginning in the first decade in which water quality is thought to have significantly impacted height, and a zero for previous decades. The variable will be different for each country in the sample and is broadly defined, whether using sources related to water filtration techniques, water sources, or sewage systems.

While experiments with water improvements began as early as the eighteenth century, the techniques were sparsely used until the end of the nineteenth century, and in some cases the beginning of the twentieth century, in this sample of countries. Poor water quality has been connected to cholera and typhoid outbreaks. The coefficient on water would be expected to be positive, as an improved water supply diminishes the risk for disease and allows the body to use food for growth instead of fighting disease.

The resulting magnitude and sign of the coefficient on the water variable will add to the debate on the causes of the improvement in nineteenth century American health, evidenced in part by falling mortality rates and the decline of the ‘urban penalty’, or higher mortality rates observed in urban areas. Fogel (1994, 2004) emphasizes the role of income, food supplies, and chronic malnutrition as reasons for the decline. Ewbank and Preston (1990) suggest that improvements in American sanitation in daily life, such as

⁶ See Appendix A for a lengthy discussion of the relevance of the variable and how the decade was selected for each country.

hand washing and breastfeeding, played an important role in the reduction of both mortality rates and urbanization. Other studies point to education as a factor in the health improvements, as a relationship has been found between the health of children and the education level of the mother (Deaton and Paxson, 2001). Meeker (1972) and Preston and Haines (1991) underline the role of the public health movement as an important determinant in the improvement in health, especially stricter perishable food inspection regulations and technologies leading to a cleaner public water supply and sewage systems. Cain and Rotella (2001) present evidence of a link between mortality and municipal sanitation spending and Preston and van de Walle (1978) highlight the building of water and sanitation infrastructures as the impetus for declining mortality rates in parts of France.

The independent variables used thus far could be considered the usual suspects, with the exception of the water variable, which we created. They are the most obvious variables to include when searching for reasons behind fluctuations in height and show up repeatedly in the literature (see, for example, Craig and Weiss and Haines et al.). But is the list complete, or is there a renegade variable lurking in the background? We contend that another variable should be considered: coal production. While on first glance the variable may seem ad hoc, it is only ad hoc in the sense that it does not heavily populate the literature. However, after considering the negative health externalities it can generate or its potential as a proxy for economic growth, it would seem to be a logical fit in a discussion involving the physical benefits and costs associated with economic activity.

Coal production was found to have a significant effect on height in the United States over the period 1870-1890 (Chanda et al. 2005). Clark and Jacks (2006) found that coal should be included among the revolutionized industries of the Industrial Revolution but that its contribution to the overall productivity growth in the Industrial Revolution in England was insignificant. While it did not appear to contribute to the productivity growth in England, is it possible that coal production significantly affected height in the nineteenth century in a larger sample of countries?

It is conceivable that industrialization, as represented by, say, the rise of the coal industry affected stature. The coal industry witnessed remarkable growth in the last quarter of the nineteenth century, especially in Belgium, France, United Kingdom, United States, and Germany. As railroads expanded trade opportunities, investors sought to increase the number of coalfields to take advantage of the boom (and consumed coal themselves). As industrialization began to take hold, coal was perceived to be a necessity of modern-life. The coal industry venture was lucrative and contributed to the rising incomes of the times, but the coal industry boom was accompanied by a host of negative externalities.

There is not a clear expectation concerning the sign on coal production. The coefficient could be positive if coal production is a proxy for overall economic growth. The coefficient could be negative if it is dominated by the presence of negative health externalities. Environmental and health concerns related to the coal industry are present even in modern times. New technology has spawned equipment capable of removing most of the polluting element from coal smoke. There is little evidence of smoke at contemporary coal plants. The coal smoke produces sulfur oxide and carbon dioxide,

both of which are considered environmentally offensive.⁷ Coal workers were more prone to suffer from consistent smoke inhalation and acute respiratory disease. Among the poorest segment of society, increased environmental pollution and its associated diseases would have negatively influenced the body's ability to relegate nutrients for growth. When the body is more susceptible to disease or sickness, net nutritional status suffers and the amount of nutrients available for growth diminishes.

Results

Table 1.1 reports the results of two regression models based on Equation 1.⁸ Column 1 shows a basic regression including death rates, GDP, urbanization, the water dummy variable, coal production and transportation with country and year fixed effects. No interaction variables were included in Column 1. The regression explains almost 94 percent of the variation in stature and all variables except coal production are significant and most are significant at the one percent level.

As expected, the results show a significant and negative relationship between death rates and stature. An increase of 2 deaths per thousand would result in an approximate reduction of stature of 0.17 of an inch. GDP had a positive and significant impact on height. As per capita income increases by \$1,000, stature would have risen by 0.6 of an inch. The urbanization variable has the expected negative coefficient, implying

⁷ Especially carbon dioxide, as it is one of the five major greenhouse gases contributing to the greenhouse effect.

⁸ Regression diagnostics were examined on all models. The residuals appeared to be normal with homogenous variance, but they did not appear to be independent. The autocorrelation was addressed using a robust covariance matrix estimator, known as the cluster-correlated robust estimator. The estimator is a variant of the Huber/White/Sandwich variance estimator specifying that observations are independent across groups but not necessarily independent within groups, which allows for serial correlation within groups. For additional information on the cluster-correlated robust estimator, see Rogers (1993) and Williams (2000). All results below are reported with these adjusted standard errors.

that if urbanization increased by 5 percentage points, stature would fall by 0.58 of an inch. The water dummy variable is also significant and positive. As healthy water supplies were secured, height increased by 0.44 of an inch. The transportation variable is negative and significant, though quite small in magnitude, and indicates that transportation improvements came at a cost. An increase of 7,500 kilometers of railway line open translates a reduction of stature of 0.04 of an inch. The coefficient on the coal production variable was positive, though not significant.

Column 2 in Table 1.1 shows the regression results using variables from Column 1 and the urbanization and GDP interaction variables. Death Rates and the water variable are both significant with the expected signs. Transportation is insignificant in this model, though it does have a negative coefficient. Coal production is both positive and significant. An increase in coal production by 100,000 metric tons would have resulted in a stature increase of approximately 0.84 of an inch.

The positive coefficient could be the result of the international coal trade. While complete data is not available on the coal trade for all countries in the sample, the coal trade could partially explain the positive coefficient on coal production. If coal were traded between countries, the negative health effects would be lower for the exporting country, as they are essentially “trading” the effects to another country.⁹ Additionally, there are potentially positive health effects associated with coal consumption. For instance, coal is frequently used for heating purposes. A warmer environment would raise the body’s temperature, allowing the body to provide more nutrients for growth

⁹ Assuming they are not importing more than they export.

since the body does not have to work as hard to stay warm. This would be especially true in colder environments.¹⁰

Urbanization Interaction Variables

All of the interaction variables are significant; meaning the coefficient on urbanization differs significantly between Germany and the remaining countries in the sample. While the coefficients on the urbanization interaction variables are significant, it is not possible to examine the country-specific effects of urbanization with the existing coefficient and standard error estimates. The estimated effects of being in one of the country categories included in column 2 of Table 1.2 are constructed by summing appropriate pairs of coefficients. The urbanization slope within each country is the sum of the urbanization coefficient and the country urbanization interaction coefficient. Table 1.2 directly tests whether there are significant urbanization country effects.

When compared with other countries in the sample, urbanization in the United Kingdom, Belgium, the Netherlands, and the United States appears to have had the largest impact on height. The coefficient on urbanization in the United Kingdom is -0.353 , thus if urbanization increased by 5 percent, height would fall by almost 0.7 of an inch. The urbanization interaction variable with the Netherlands was negative and significant with an urbanization coefficient of -0.25 . If urbanization in the Netherlands increased by 5 percent, height would have decreased by 0.49 of an inch. Similarly, the interaction variable with the United States was negative and significant, suggesting that a 5 percent increase in urbanization would result in a height decrease of 0.25 of an

¹⁰ If coal production is a proxy for economic growth, then the inclusion of both as independent variables could result in an identification problem, as the coal production variable could be picking up GDP effects.

inch. The interaction variable with Belgium was positive and significant with a positive coefficient of 0.439, implying that a 5 percent increase in urbanization would result in a height increase of almost 0.87 of an inch.

The negative urbanization impact on height is not surprising in the United Kingdom, the Netherlands, and the United States. The percentage of the population residing in urban areas was the highest throughout the nineteenth century in these countries. Crowding in urban areas and the lack of public health measures for much of the century would have contributed to the negative relationship between urbanization and height. While the result in Belgium is unexpected, the exceptionally high coefficient for Belgium could reflect the fact that data are not available for this country in the early part of the nineteenth century. Data for Belgium are not available after 1880, and it is possible that urbanization's impact on height would have been greater in the last part of the century.¹¹

The urbanization interaction coefficients in the remaining countries were not significant, implying that although urbanization has an overall significant effect on height (net of other independent variables), urbanization does not reliably improve the prediction of average height in France, Sweden, Germany, and Denmark. Therefore, after controlling for the urbanization effect across countries, urbanization was positively correlated with height in Belgium and the negative health effects associated with urbanization were more severe in the United Kingdom, the Netherlands, and the United States.

¹¹ In fact, when the sample is restricted to include only those decades that coincide with the available Belgian data, the urbanization coefficient is positive but insignificant.

GDP interaction variables

The estimated country GDP effects are reported in column 1 of Table 1.2 and are constructed in the same manner as the urbanization interaction variables. The GDP slope within each country is the sum of the overall GDP coefficient and the country GDP interaction coefficient. Table 1.2 directly tests whether there are significant GDP country effects.

There were significant GDP effects in the United States, United Kingdom, Belgium, and the Netherlands. The coefficient on GDP in the Netherlands is 0.0025, thus if GDP increased by \$1,000, height would increase by approximately 0.98 of an inch. Similarly, an increase in income of \$1,000 per capita would increase stature in the United Kingdom by 0.59 of an inch. A positive coefficient on GDP implies that increases in income were accruing to people who had not yet reached their genetic potential with respect to stature and whose income choices were contributing positively to their growth. When compared with other countries in the sample, GDP appears to have impacted height the least in Belgium, Germany, and the United States. An increase in income of \$1,000 per capita would have decreased stature by 1.46 inches in Belgium and 0.83 inches in the United States.

The negative relationship between GDP and height suggests several possibilities. The first is that increases in income were accompanied by jobs requiring hard labor, thereby increasing demands on the body and diverting nutrients from growth to body maintenance. A second possibility is that when compared to other countries in the sample, a greater proportion of their incomes were spent on alcohol, tobacco, and sugar. Of course, any combination of the two would negatively affect stature as well. In a

comparative sense, there were larger biological costs associated with rising GDP in the United States and Belgium.

The sign on GDP should be smaller in countries that spent more of their income on goods negatively related to health. According to Clark et al., higher incomes were spent, at least partly, on alcohol, tobacco, sugar, and in general less healthy diets in the United Kingdom (Clark et al. 1995). Clark et al. also suggests there may have been significant diet differences between rural and urban areas, as rural areas would have consumed more protein-rich foods, such as grains, milk, and cheese, and urban areas would have relied more on processed foods. Therefore increases in height from rising GDP would have been limited by their access to healthy foods. It seems this pattern was not unique to the United Kingdom and was most pronounced in Belgium and the United States. Therefore, following Clark et al. (1995), the GDP effect could vary by country, if income decisions in these countries were unhealthier than the decisions made by other countries in the sample.

While the GDP coefficient was positive and significant for the United Kingdom, this is not evidence against the Clark et al. theory. It is possible that the GDP coefficient could have been even larger had British consumers spent their income in a different manner. The GDP effect was not significant in the Sweden, Denmark, Germany, or France, suggesting that although GDP has an overall significant effect on height, GDP does not reliably improve the prediction of average height in these countries.

Conclusions

The period 1800-1920 was characterized by industrial growth, urbanization, and the steady rise of gross domestic product, but society's general well-being cannot be assessed using GDP alone. Stature is an important supplemental measure to assess the standard of living. It is an especially important measure in this time period because it can reflect the physical benefits and costs associated with increased economic activity (Cuff 2005).

This study examines both economic and health determinants of stature over a cross-section of countries. Economic growth, as measured by GDP and coal production, significantly affected stature. Coal production served as either a proxy for industrialization, a reflection of international trade, or as an improvement to health that overwhelmed the negative externalities generally thought to accompany the practice. The GDP effect varied by country and was least beneficial in the United States and Belgium. In fact, GDP and height were negatively correlated in these countries, implying that GDP increases were spent in large part on unhealthy purchases. Urbanization effects also varied by country. The negative stature effects were most severe in the United Kingdom and the Netherlands. The physical costs generally associated with increased levels of urbanization were not present in Belgium. There is some evidence that transportation negatively affected stature. Death rates were consistently and negatively related to stature.

The results confirm the importance of both economic and health related variables in studying fluctuations in stature and the evidence supports the positions of both Fogel and Deaton. The study also expands the usual country-specific explorations and reveals

estimates of a global set of biological coefficients. In other words, the study seeks to make a global statement regarding the economic and non-economic variables that affect stature.

The possibility that securing healthy water supplies can significantly impact height receives support here. The water supply variable was positive and significant, possibly implying that securing healthy water supplies decreased the incidence of disease, allowing the body to use nutrients for growth instead of fighting infection. The construction of the water variable provides the first empirical estimate of water supply as it relates to height for a cross-section of countries. While the variable in its current form is not beyond criticism, it provides a stepping-stone to obtaining more concrete evidence of its impact on height. The variable deserves future study and gives empirical support to the premise that public health measures significantly improved health, through height, over the nineteenth and early twentieth centuries.

Overall, it seems height is affected by a common set of factors across countries, including GDP, urbanization, death rates, transportation, water supply, and coal production. The fluctuations in stature generate coefficients that offer a broader picture of what affected height over the period 1800-1920. Future research plans include the expansion of the data set to include more countries and an empirically-based water supply variable.

Table 1.1 Regression Results**Dependent Variable: Height (in centimeters)**

Parameter	1		2	
	Estimate	Approx Std Err	Estimate	Approx Std Err
Intercept	177.495089***	1.71648579	171.6272***	2.1790
Death Rates	-0.216381***	0.06316553	-0.2209***	0.0717
GDP	0.001535**	0.0007356		
Urbanization	-0.295096***	0.04975089		
Water	1.135213*	0.5377743	0.6482*	0.3206
Transportation	-0.000015***	0.00000197	-0.00001	0.00001
Coal Production	0.005375	0.00483762	0.0213***	0.0020
Country and Year Fixed Effects	Yes		Yes	
R ²	0.935		0.9792	
Observations	75		75	

Notes: Adjusted standard errors are reported. GDP and urbanization country effects from the second specification are reported in Table 1.2.

*** Denotes significance at the 1 percent level.

** Denotes significance at the 5 percent level.

* Denotes significance at the 10 percent level.

Table 1.2: Net Effects of GDP and Urbanization on Height by Country

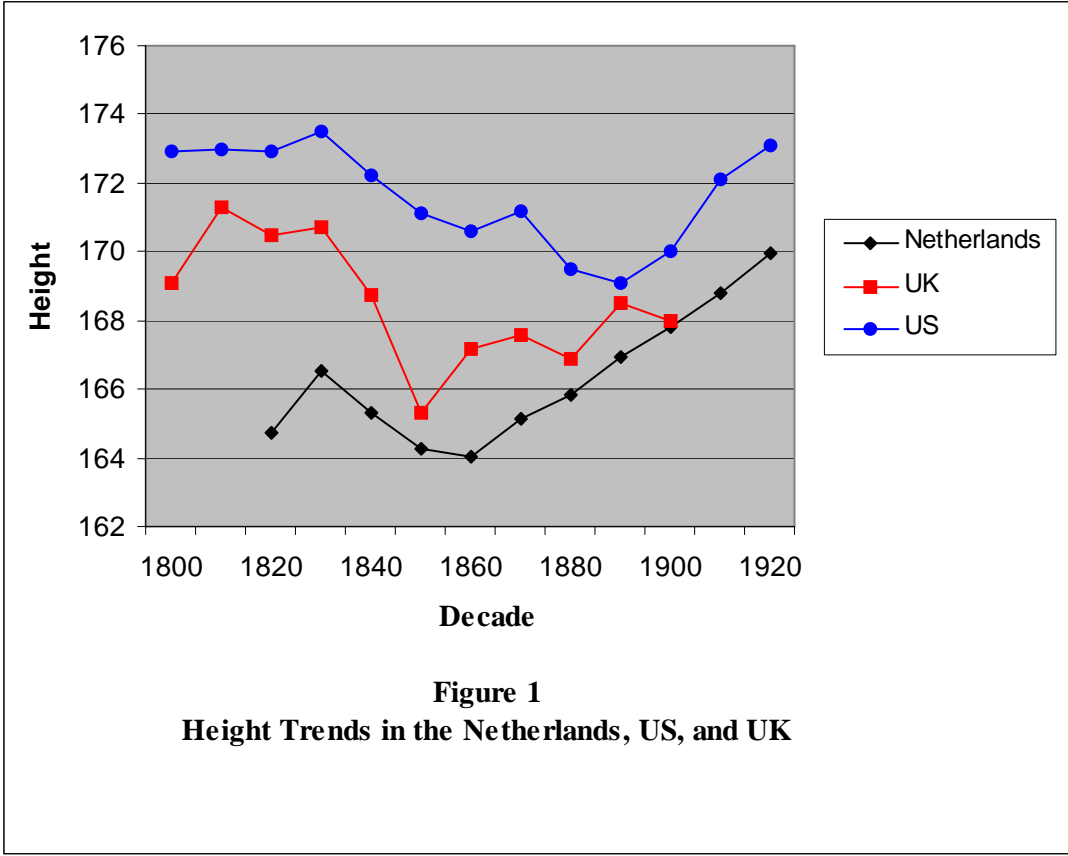
Country	GDP 1		Urbanization 2	
	Estimate	Approx Std Error	Estimate	Approx Std Error
US	-0.0021**	0.0007	-0.1269*	0.0544
UK	0.0015*	0.0005	-0.3529***	0.0466
Sweden	-0.0001	0.0013	0.1272	0.1128
France	0.0020	0.0015	-0.0964	0.1192
Netherlands	0.0025**	0.0010	-0.2500*	0.1200
Belgium	-0.0037**	0.0015	0.4393*	0.1605
Germany	-0.0053	0.0020	-0.0053	0.0029
Denmark	-0.0017	0.0021	0.1480	0.1741

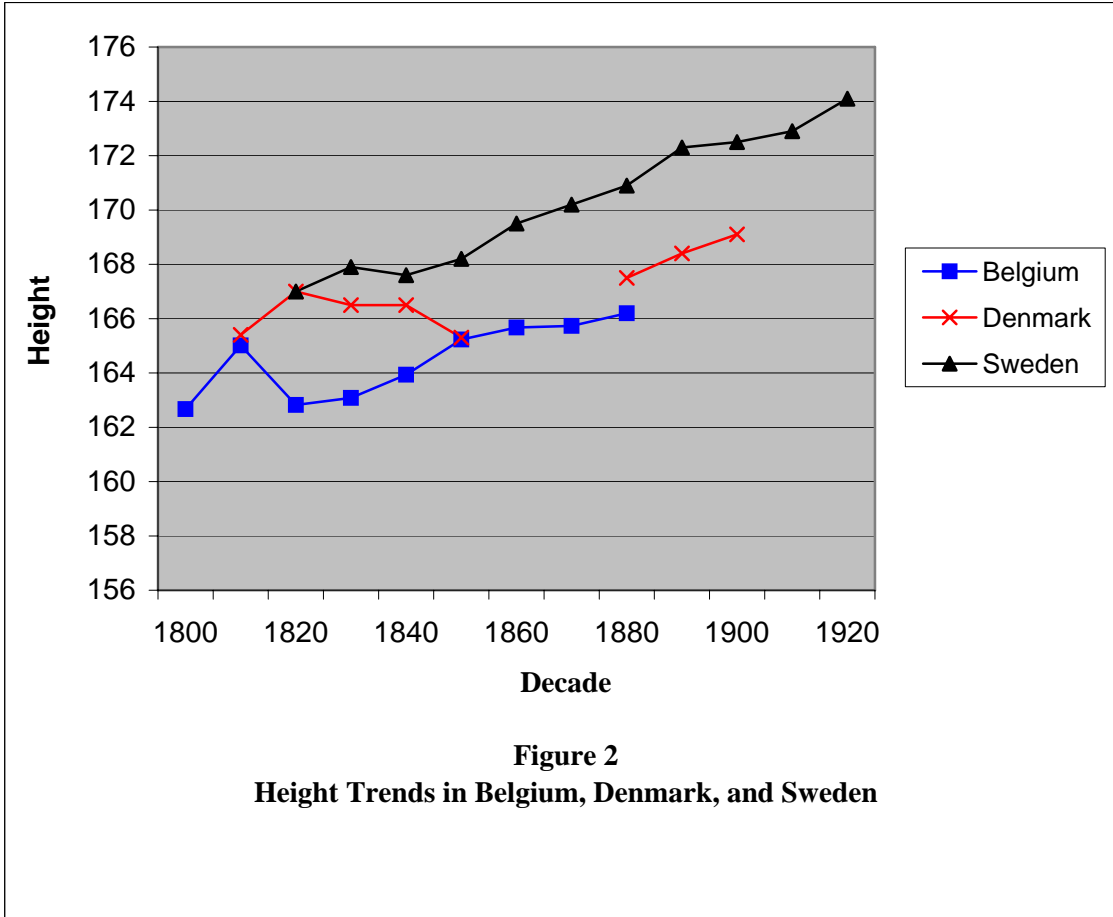
Notes: Entries for each country were calculated by summing coefficients; standard errors were calculated as $[\text{var}(\beta_i) + \text{var}(\beta_j) + 2\text{cov}(\beta_i, \beta_j)]^{1/2}$.

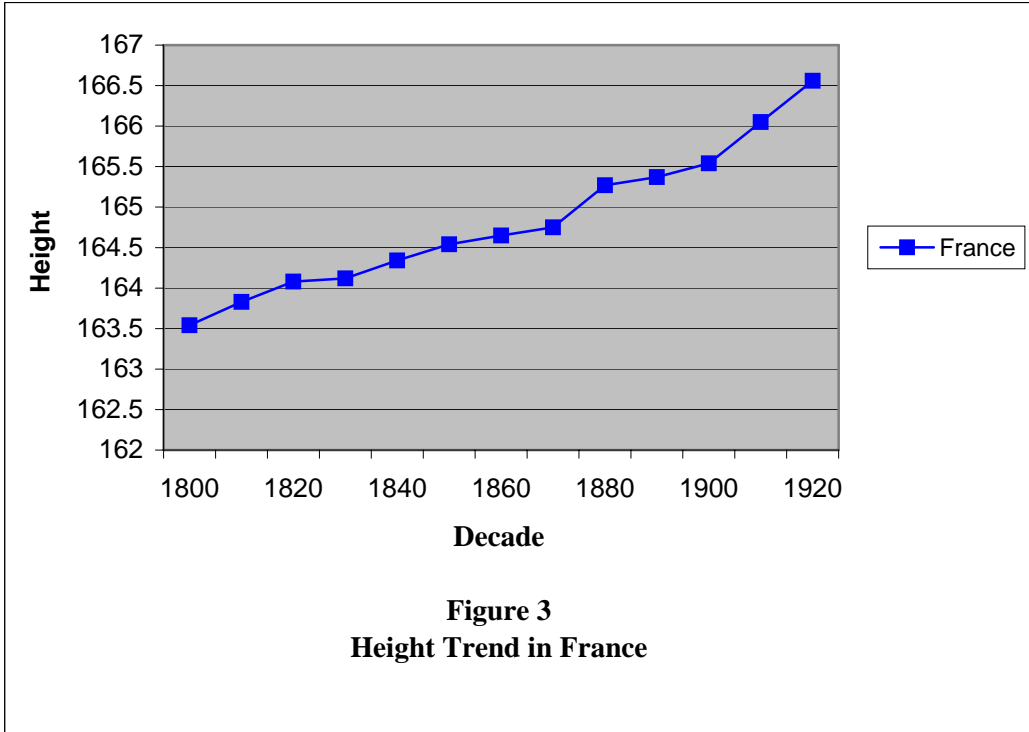
*** Denotes significance at the 1 percent level.

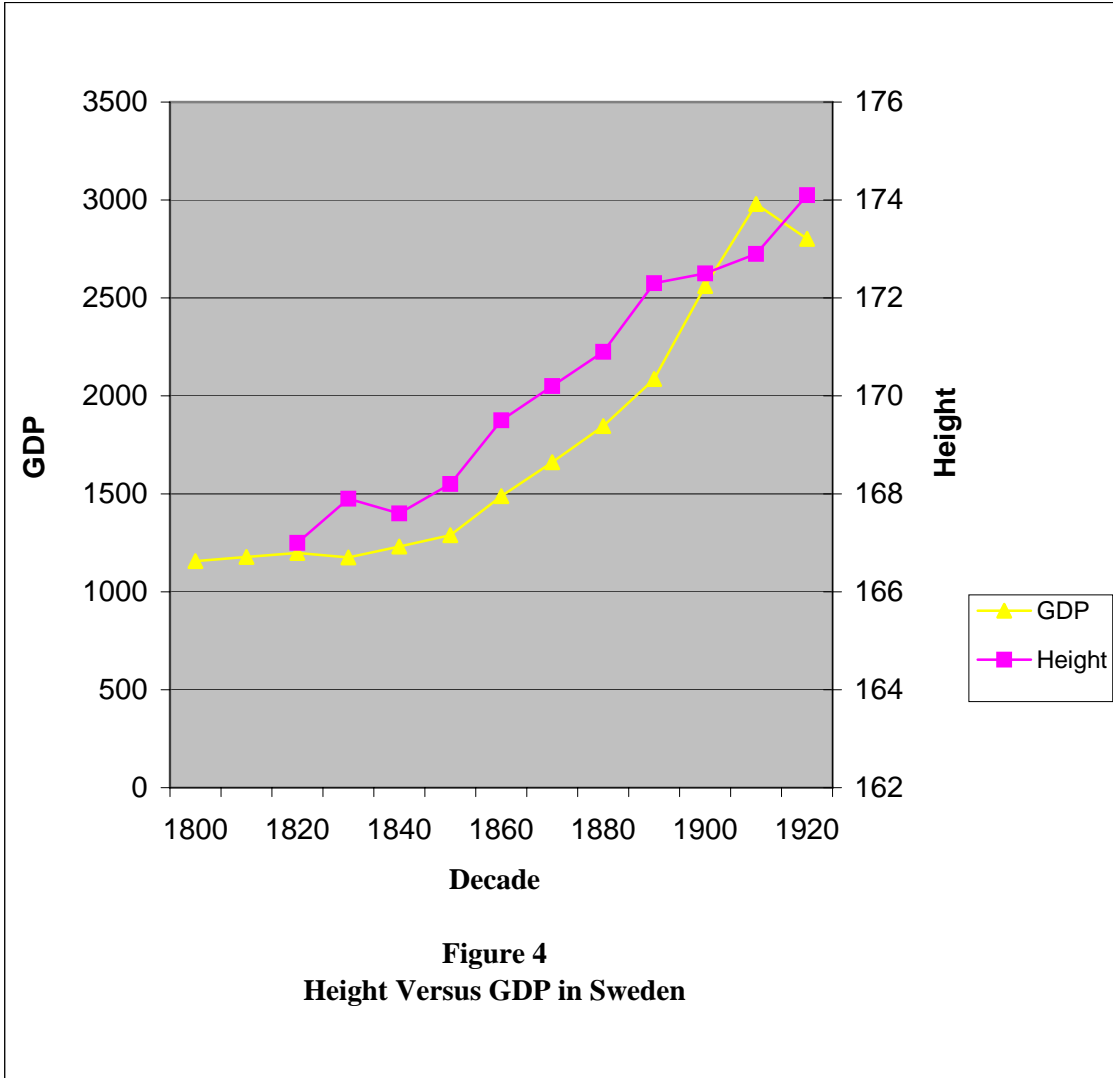
** Denotes significance at the 5 percent level.

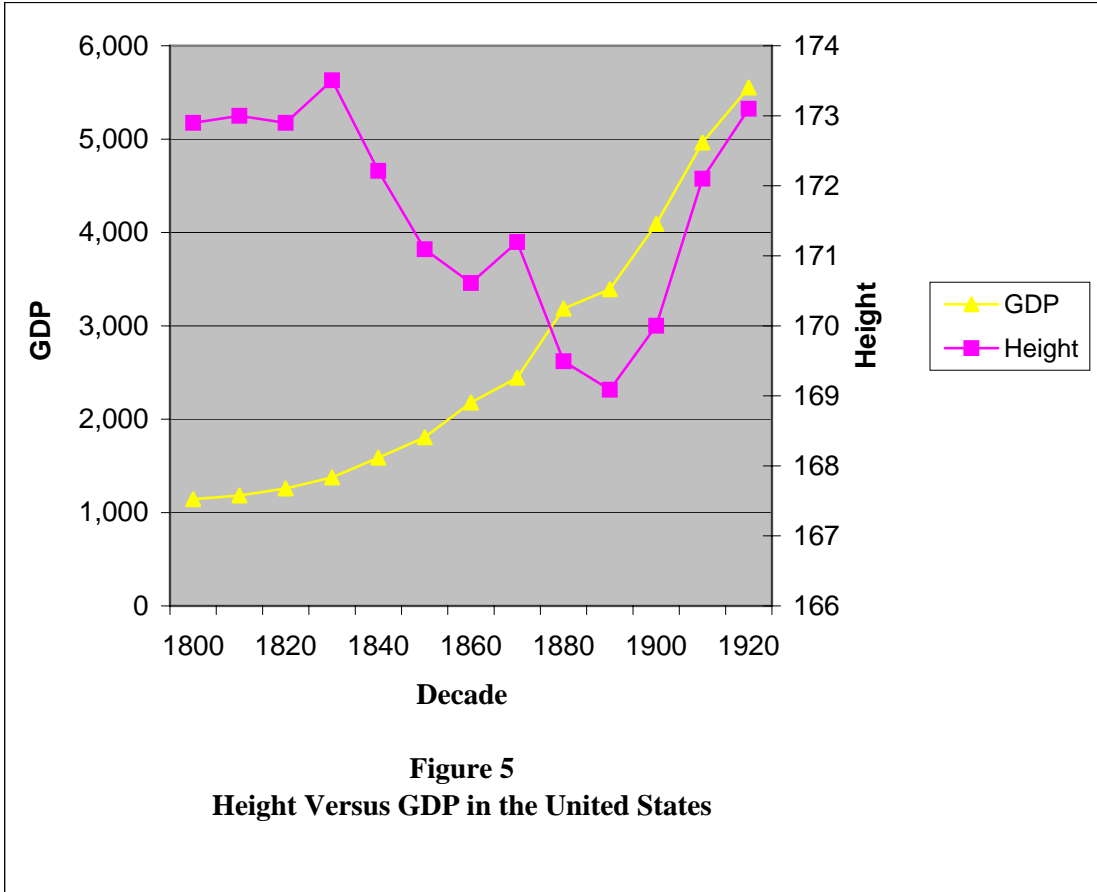
* Denotes significance at the 10 percent level.

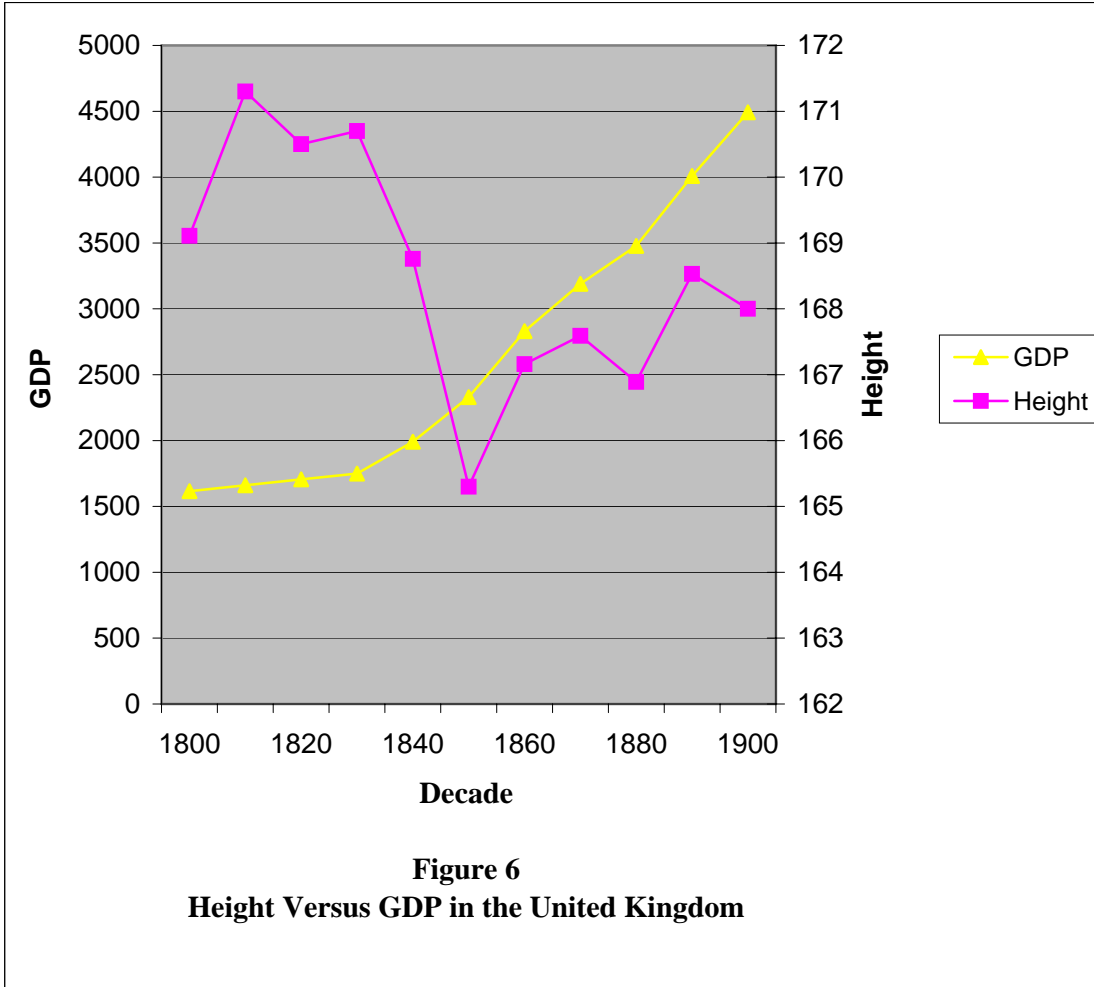


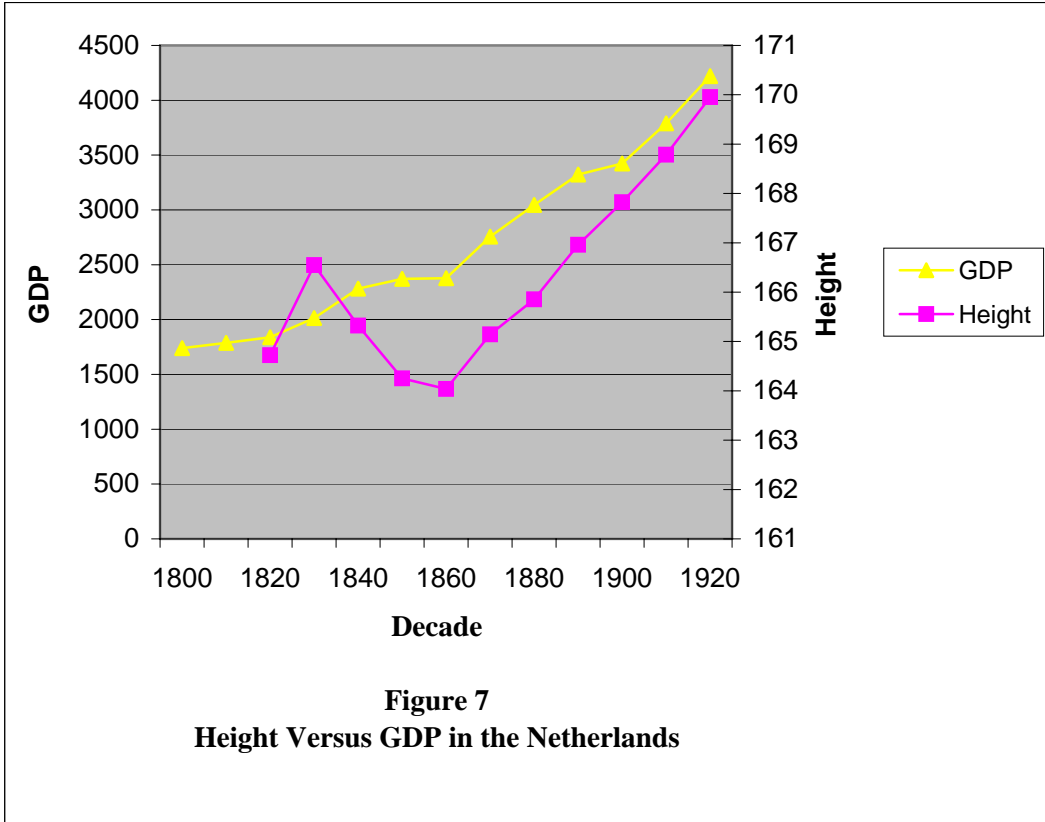


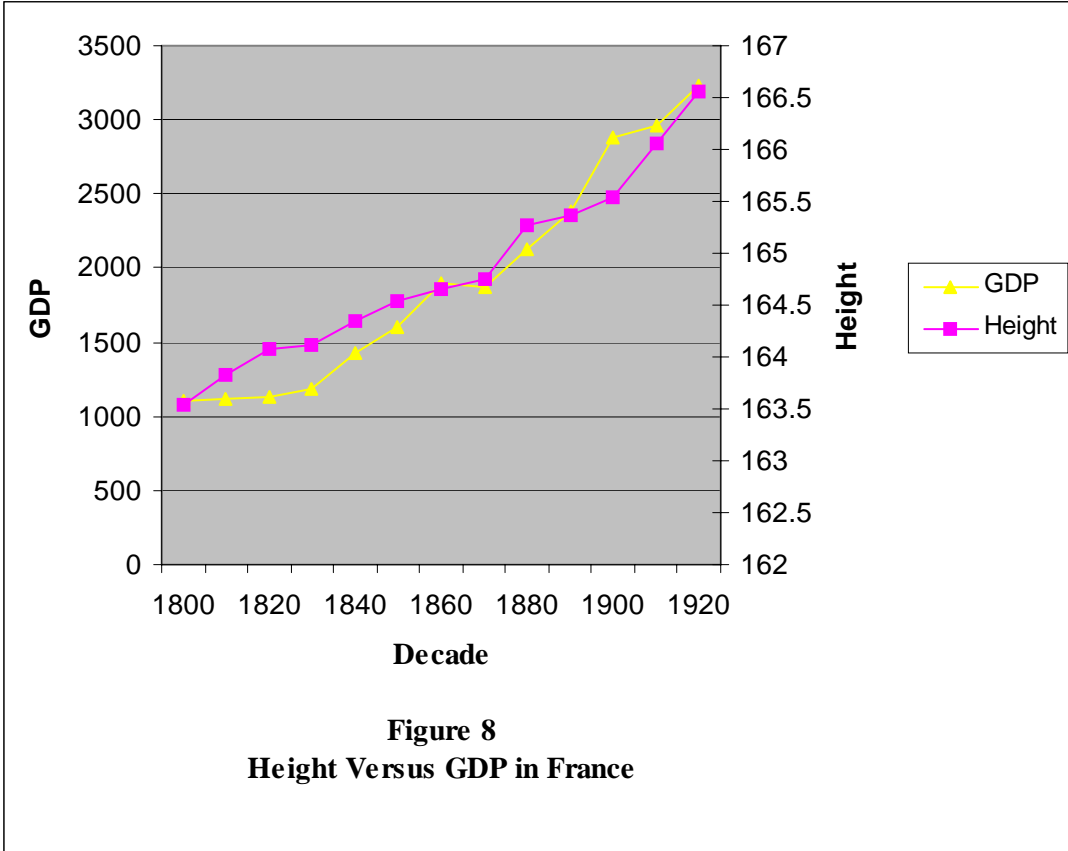


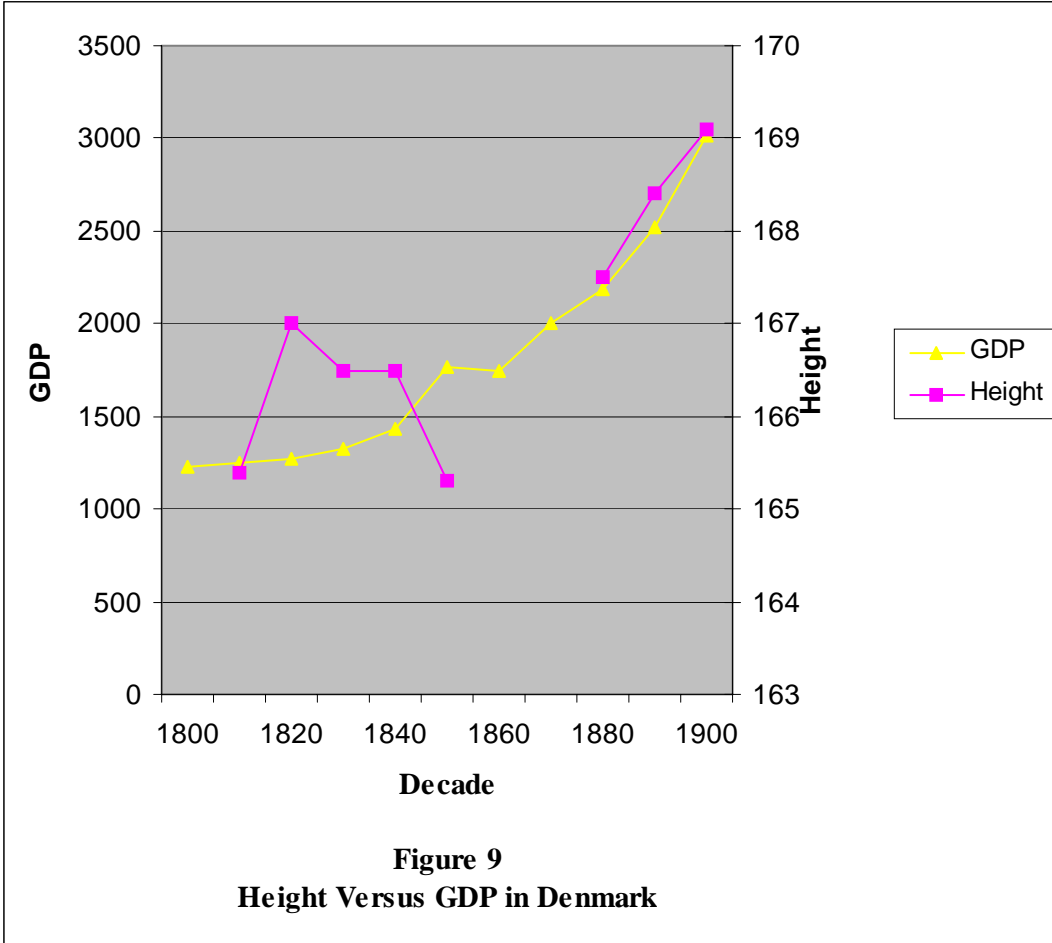


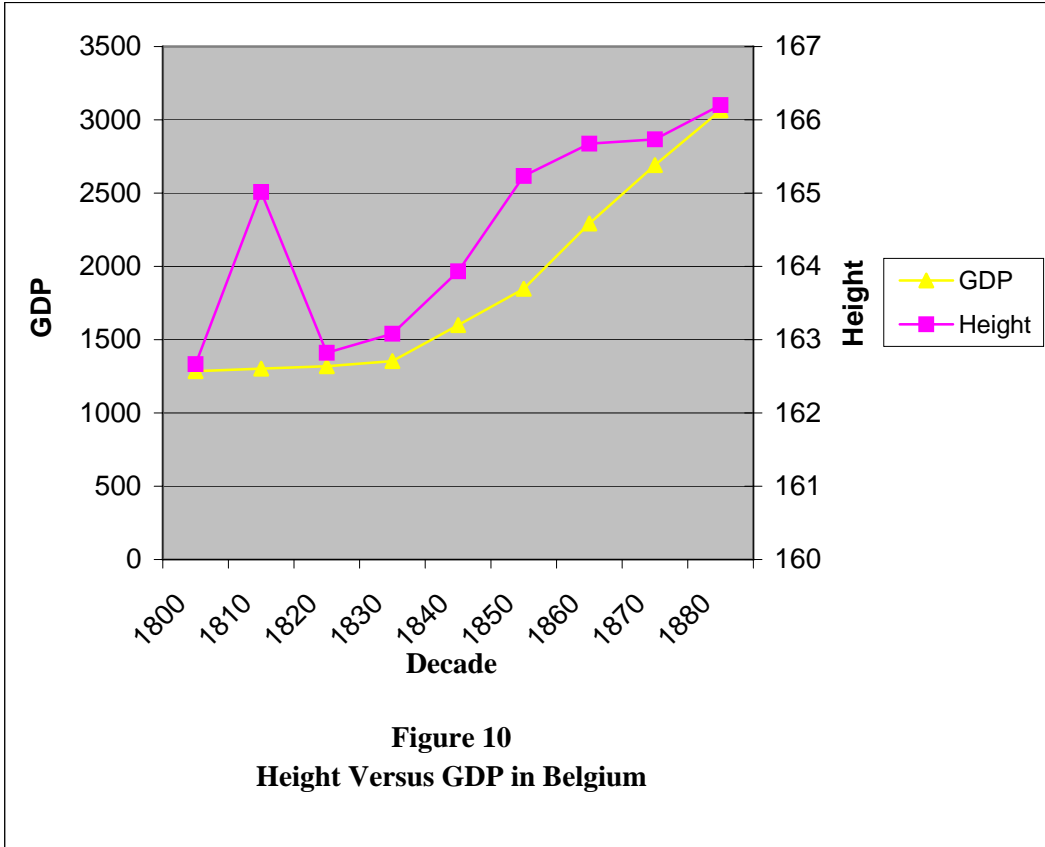












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3. Appendix

3.1 Description of the Data

Table 3.1
Male Height for Individual Countries

Decade	Belgium	Denmark	France	Germany	Netherlands	Sweden	UK	US
1800	162.67		163.54				169.11	172.90
1810	165.01	165.40	163.83				171.30	173.00
1820	162.82	167.00	164.08		164.72	167.00	170.50	172.90
1830	163.08	166.50	164.12		166.55	167.90	170.70	173.51
1840	163.93	166.50	164.34		165.32	167.60	168.76	172.21
1850	165.23	165.30	164.54	169.15	164.25	168.20	165.30	171.09
1860	165.68		164.65	169.25	164.04	169.50	167.16	170.61
1870	165.73		164.75	169.33	165.14	170.20	167.59	171.20
1880	166.20	167.50	165.27	169.65	165.86	170.90	166.89	169.49
1890		168.40	165.37	169.70	166.96	172.30	168.53	169.09
1900		169.10	165.54		167.82	172.50	168.00	170.00
1910			166.05		168.79	172.90		172.10
1920			166.56		169.95	174.10		173.10

Sources: In cases where no data were available for the decades listed, figures have been reported for the next closest year. Belgium: Alter et al (2004); Denmark: Floud (1984); France: Weir (1997); Germany: Twarog (1997); Netherlands: Drukker and Tassenaar (1997); Sweden: Sandberg and Steckel (1997); United Kingdom: Floud et al (1990); United States: Steckel (2002).

Table 3.2
Percentage of the Population Residing in Urban Areas for Individual
Countries

Decade	Netherland							
	Belgium	Denmark	France	Germany	s	Sweden	UK	US
1800	20.5	20.9	12.2		37.4	9.8	33.8	6.1
1810	(22)	20.8	(13.36)		(36.86)	9.8	36.6	7.3
1820	(23.5)	20.7	(14.53)		(36.31)	9.8	40	7.2
1830	25	20.6	15.7		35.8	9.7	44.3	8.8
1840	(29.25)	20.5	16.2		(35.7)	9.7	48.3	10.8
1850	33.5	20.9	19.4	26.8	35.6	10.1	54	15.3
1860	34.8	23.4	22.13	29.4	(38.248)	11.3	58.7	19.8
1870	36.9	24.9	25.7	32.5	(40.9)	13	65.2	25.7
1880	43.1	28.1	27.6	35.6	44.5	15.1	(70)	28.2
1890	47.7	33.2	30.4	39.4	(46.15)	18.8	(74.5)	35.1
1900	52.3	38.2	35.4		47.8	21.5	(78)	39.6
1910			38.5		50.5	24.8	(79.11)	45.7
1920			40.33			29.5	(80.33)	51.2

Notes: In cases where no data were available for the decades listed, figures have been reported for the next closest year. Figures in parentheses are interpolations. Decades left blank were not used in the analysis because of lack of data for other independent variables.

Sources: Belgium: Bairoch and Goertz (1986) and Craig and Fisher (1997); Denmark: Weber (1889), Craig and Fisher (1997); France: Weber (1889) and Bairoch and Goertz (1986); Germany: Craig and Fisher (1997); Netherlands: Bairoch and Goertz (1986); Sweden: Weber (1889) and Berry and Horton (1970); United Kingdom: Williamson (1988) and Berry and Horton (1978), Numbers in Parentheses are interpolations calculated using the urbanization level in 1870 from Williamson and applying the growth rate of Berry and Horton for subsequent decades; United States: Dodd (1993).

Table 3.3
Death Rates for Individual Countries

Decade	Belgium	Denmark	France	Germany	Netherlands	Sweden	UK	US
1800		28.5	27.7			31.4	27	28.15
1810		22.7	24.9			31.6	27	29.6
1820		20.9	25.4			24.5	23	25.87
1830	25.6	25.3	25			24.1	20	27.73
1840	25	21	23.7		23.5	20.4	22.9	25.42
1850	21.2	19.1	21.4	25.6	22.2	19.8	20.8	22.95
1860	19.9	20.2	21.4	23.2	24.8	17.7	21.2	23.76
1870	23.6	19	28.4	27.4	25.9	19.8	22.9	23.66
1880	22.3	20.4	22.9	26	23.6	18.1	20.5	21.34
1890	20.8	19	22.8	24.4	20.5	17.1	19.5	19.44
1900	19.3	16.8	21.9		17.9	16.8	18.2	17.27
1910			17.8			14		15.7
1920			17.2			13.3		11.08

Sources: Belgium, Denmark, France, Germany, Netherlands, Sweden, and United Kingdom (Mitchell, 1992); United States: 1870-1920 (Craig 1989), 1800-1860 (Treme, 2006).

Death rates for the United States were not available for the decades prior to 1870. The problem is how to estimate these with existing data. The rate of natural increase prior to 1870, or the crude birth rate – crude death rate, has already been estimated as a residual (Craig 1989). Therefore, if the crude birth rate and the rate of natural increase can be estimated, an algebraic manipulation will result in an estimate of the crude death rate. Using crude birth rates from (Haines 2005) and the rate of natural increase prior to 1870 from (Craig 1989), crude death rates were estimated. The data used in the process are shown below.

Table 3.4**Estimates of United States Death Rates**

Decade	Crude Birth Rate (CBR)	Rate of Natural Increase (RNI)	Crude Death Rate (CBR - RNI)
1800	55	26.85	28.15
1810	54.3	24.70	29.60
1820	52.8	26.93	25.87
1830	51.4	23.67	27.73
1840	48.3	22.88	25.42
1850	43.3	20.35	22.95
1860	41.4	17.64	23.76

Notes: Crude Birth Rates (Haines 2005); Rate of Natural Increase (Craig 1989).

Transportation

The transportation variable reflects the length of railway line open (in kilometers) from Brian Mitchell (1992, 2003).

Coal Production

Coal production is measured by the output of coal (in metric tons) for each country.

Gross Domestic Product

This series consists of data for gross domestic product from Angus Maddison's website, derived from the upcoming book, Contours of the World Economy. The figures are in 1990 International Geary-Khamis dollars. In a small number of cases there were no GDP calculations and interpolations were made to obtain estimates.

Water

While much has been made of the significance of proper diet in achieving genetic height potential, water quality is just as important. Since the body is made up of over 70 percent water, the quantity and quality of water is a key component of health. In a biological sense, optimal water consumption aids in proper excretion, circulation, and digestion. Water contributes to the processes by helping to form cells, which absorb vitamins, nutrients, and minerals and transport them to the parts of the body where they are needed. Proper consumption of water prevents dehydration, contributing to increased heart and respiration rates.

Tainted water supply spreads bacteria and viruses and negatively affects the overall quality of life by preventing the body from performing vital functions and making it vulnerable to sickness and life-threatening disease. In terms of growth, children would be greatly affected, as the vitamins and nutrients would be diverted from growth and forced to fight disease and perform basic body maintenance. In other words, poor water quality diminishes net nutritional status. The length and severity of the sickness or disease will determine if the child is permanently thrown from his growth path and repeated episodes of water-related illnesses can result in stunting. In addition, many diseases can have a depletion effect, increasing individual susceptibility to other infections (Baldwin 1999).

In the last decades of the nineteenth century, Juuti and Katko report that over 600 epidemics spread throughout Europe and it is estimated that water-borne diseases caused

70 percent of these (2006). Victor Hugo even references the problem of water supply quality in *Les Miserables* when he writes of the “blindness of a bad political economy” that allowed human waste to contaminate the water. Typical nineteenth century water-related illnesses include diarrhea, cholera, hepatitis A and typhoid. It is important to note that while each illness can be transmitted by other means (food), water transmission can be especially devastating because it can spread the disease to large numbers of people. Today, diarrhea is still one of the top killers of children, usually through drinking supplies tainted by human excrement and solid waste, and severe acute respiratory syndrome (SARS) has been linked to deficient water supplies.¹²

Cholera and typhoid outbreaks were deadly in both Europe and North America in the nineteenth century. Cholera can be transmitted through impure water sources or uncooked food and causes diarrhea, severe dehydration, and if left untreated, can result in death. Outbreaks are especially devastating to urbanized cities and have been most severe when populations were growing rapidly and poor water infrastructure was in place. Coastal areas were vulnerable to cholera outbreaks, as shipping routes in the nineteenth century commonly transmitted the disease.¹³

Salmonella typhi, or germs of human excreta cause typhoid. Typhoid can cause fever, headache, rash and diarrhea and death if not properly treated. If a patient does not die from typhoid, his body can be permanently damaged, specifically his cardiovascular, respiratory, gastroenterological, and neurological systems (Troesken 2004). This of course can lead to an achieved adult height far below his genetic potential. It is spread most frequently by contaminated water, but infected food can also be the culprit. Hardy

¹² http://www.makingcitieswork.org/urbanThemes/Urban_Health/Urban_Environmental_Health

¹³ Baldwin (1999), page 63.

(1993) suggests that it is likely that contamination of water supplies was the means by which the majority of the typhoid cases were contracted. Once these germs enter the water supply, outbreaks are inevitable because of its high contagion factor. Preventative measures include extending of public water and sewer line, installing water filters, and chlorinating water (Troesken 2004). Typhoid and cholera differ in that typhoid is a local and domestic problem (Hardy 1993).

In the first half of the nineteenth century, many cities used prime water sources as a dumping site for human and industrial waste. The general consensus was that the flow of the water would abate the negative health effects of the waste. It was only in the later half of the century that the connection between poor water quality and cholera and typhoid outbreaks was made. In a dramatic experiment, John Snow demonstrated the connection by closing the pump in one of the most affected areas of London. The result was equally as dramatic, as the number of new cholera cases plummeted.

The purpose of the water supply variable is to determine when healthy water supplies were secured in each country by identifying the decades in which the application of water filtration techniques and the evolution of water systems would have been most likely to have a positive and significant effect on height in urban areas. In other words, the dummy variable will take on a value of 1 beginning in the first decade in which water quality is thought to have significantly impacted height and a zero for previous decades. The variable will be different for each country in the sample and is broadly defined, whether using sources related to water filtration techniques, water sources, or sewage systems.

However accurate the date is pinpointed, there remains the possibility that the dummy variable is capturing simultaneous public health events occurring in each country. Admittedly, the criteria are subjective, but in absence of empirical data for each country in the sample, the approach seems reasonable. There was a general upward trend in height in the late nineteenth century and early twentieth century, independent of evolving water quality and access. To separate the effect of improvements in water supply from the general upward trend in height, decade dummy variables will be included with the water supply variable.¹⁴

Water Supplies

Public water supplies began to appear in the nineteenth century as a supplement or replacement to private water companies. Since private water companies often sporadically served very small areas, large portions of the population went without water. In addition to personal use, water was needed for sewage, street cleaning, and firefighting. To address these problems, larger towns began providing water. For instance, the Manchester and Salford waterworks company was taken over by the Manchester Corporation with the approval of Parliamentary powers in 1847 (Singer 1957). This was the pattern in other larger cities in the United Kingdom as well as other countries in Europe. Most of the urban waterworks on the continent of Europe were taken over by the local authorities by the end of the century (Hazen 1903). By 1860, all

¹⁴ Since the water variable is a dummy variable ranging from the decades 1880 to 1920, including a dummy variable for all decades would introduce significant collinearity problems. Therefore two decade dummy variables were excluded.

but four of the sixteen largest cities had municipally owned supplies in the United States (Blake 1956).

Cities looked to secure a pure water supply by drawing water from sparsely populated areas, securing ground-water, and filtration of surface waters, the basic process of water treatment (Hazen 1903, pg. 2-3). Drawing water from sparsely populated areas was primarily done in segments of England and the United States, though its usefulness is tempered by the distance to the water source. Using spring or well water that has been purified through its passage through the ground is an alternative way to obtain purified water, but generally only results in small supplies of water. Geological conditions determine how much ground-water can be secured. Several European cities, especially Paris, Vienna, and Munich, were able to draw large amounts of water from this source, but were not a large source of water for most cities. Filtration of water supplies can also purify water supplies. In 1896, water filtration techniques were used on water supplies and affected at least 20,000,000 people in Europe. (Hazen 1903, pg. 3)

Since many cities could not find large water supplies from sparsely populated areas or spring or well water, obtaining water from the filtration process took on a new importance. Troesken (2004) found there was a greater drop in typhoid death rates in cities that installed water filters. Coupled with medical advances and the emergence of bacteriology, developed in part by Louis Pasteur and Robert Koch, the importance of clean water was in the forefront of the public health movement. In 1883, Robert Koch compared bacterial growth stemming from tap water, well water, and river water. His results suggested that a defective filter could contribute significantly to the decrease in water's bacteriological quality. In 1893, Koch showed that river water filtered using

slow sand filtration did not cause outbreaks of cholera and typhoid in Altona, Germany. In contrast, cities that did not use filtration techniques were still prone to the cholera outbreaks.

In response to the polluted Thames River, James Simpson constructed sand filters in 1829 (Baker 1981). Slow sand filtration, a type of water purification technique, was commonly used in nineteenth century Europe and to a lesser extent in the United States. Sand filtration is a type of water purification process in which water is passed through a bed of sand to filter bacteria and improve the quality of water. Modern day slow sand filters generally have four design components: the supernatant (water above the filter sand that provides hydraulic head for the process), filter sand varying in depth, the underdrain medium (usually consisting of graded gravel), and a set of control devices. Scraping the thin upper sand layer cleans the slow sand filtration. According to Rust and McArthur (1996) the supernatant ensures the raw water passes through the filter bed and creates a detention time of several hours for the treatment of raw water.

Nineteenth century slow sand filtration techniques were less sophisticated, but rested on the same principles. As water entered a typical slow sand-filter, it immediately encountered two to six feet of sand. A bed of gravel lay underneath the sand and several feet of broken and dry stone lay at the bottom to collect the filtered water. Three gallons of water passed through the filter per square foot per hour. The sand layer caught much of the debris and when the debris became too thick for the water to seep through, the top layer of sand had to be removed by hand. Rapid sand filtration techniques emerged in the 1880s. These filters used jets of compressed air admitted through underdrains to loosen the dirt (Hazen 1903).

Franklands (1894) suggested that slow sand filtration reduces the number of bacteria from river water by more than 90% to below 100/ml. The World Health Organization reports that this was the standard adopted by many European countries, while the USA adopted a 500 bacterial/ml guideline.

The United States was far less inclined to use sand filtration. The silt-laden waters of North American Rivers made it difficult to employ the sand filters. The mechanical rapid filter was developed and used in the United States in the 1880s, the notable difference being the use of mechanically driven agitators or high-pressure jets of water to purify the water (Baker 1981).

France

Water quality at the beginning of the nineteenth century was poor. Claude Rambuteau estimated that approximately 8 liters of drinkable water were available for each person per day (La Berge 1992, pg. 190). The amount of water available increased after the water canals were constructed in 1809 and many underground pipes were built. Water distribution techniques were not advanced, as most people received their water from carriers two buckets at a time or by fountains (La Berge, pg. 191). By 1850 private companies had offered to develop a more sophisticated water distribution plan, but they were met with resistance after the government considered the cost and the state of its sewage system. Ideas to reform sewers were not taken seriously until the 1870s. The lack of sanitary measures is reflected to some degree in the cholera outbreaks of 1832 and 1849.

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Large cities in France were supplied with water for domestic use from springs in several valleys at a great distance from the cities. Spring water is the purest form of water in nature as the water filters through different geological beds. The city of Grenoble began to tap large quantities of pure ground water from nearby mountains in 1884. Prior to 1892, the Parisian springs did not produce enough for the 2.5 million inhabitants who needed it. After aqueducts from springs in the valley were completed in 1892, additional spring water supplies yielded a minimum of 23 million gallons in Paris. There were 53 million gallons of spring water available on a daily basis and 21 gallons per capita. (Hazen 1895) Paris did use filtered water in the nineteenth century, but little of it was piped to houses because of the high population density and the use of cesspools. (193) Water from “natural filters” was preferred to artificial filtration techniques. It was not until the end of the century that Paris began to artificially filter its water through multiple filtration and the technique was subsequently adopted throughout France (Baker 1981). The year 1906 saw the use of ozone as a disinfectant in Nice, France.

The water dummy variable will take on a value of 1 beginning in 1890 and each decade thereafter, reflecting the decades in which application of water filtration techniques and the procurement of large quantities of water from spring would have been most likely to have a positive and significant effect on height.

United Kingdom

By the turn of the century, Parliament had authorized joint-stock companies to improve water supplies. The early efforts were commendable, but did not produce far-reaching results, as cholera epidemics hit the United Kingdom several times in the

nineteenth century. A national cholera epidemic took place in 1832. From 1840 to 1900 municipalities began taking control of many urban water supplies. While public health measures were not widely adopted in the first half of the century, sanitary concerns began to emerge on a larger scale after Edwin Chadwick's 1842 report on sanitary conditions. In fact, the Public Health Act of 1848 extended the power of local authorities to include water supply improvements. The power was not exercised to its fullest extent, as 1849 brought a second national cholera outbreak, killing 33,000 in three months (Juuti and Katko 2006).

Sewage was a problem in London, but until Parliament was directly affected, it remained low on the priority list. London's population was almost 2.5 million people at the midpoint of the nineteenth century. The Thames River was little more than a dumping site for human and industrial waste and breeding ground for cholera and typhoid. It was also the source of water for a large portion of the London population. It was not until the smell of the river interfered with Parliament meetings that the government decided to take action. Parliament met in a building next to the river and could not escape the smell, known as the Great Stink of 1858. In fact, they even tried soaking the curtains in chemicals, an early forerunner to Febreeze, to avoid smelling the river. After unsuccessfully dealing with the smell, they decided to go straight to the source and approved sewage systems to pump the sewage away from the city. One result of this was that cholera and typhoid outbreaks faded to the background.

By 1880, almost 80 percent of towns had municipally supplied water (Baker 1981). This was an advantage, as privately operated companies were more likely to serve smaller segments of the population, generally the wealthy portion or those nearest the

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water source, and were unable to provide adequate water for fighting fires and street cleaning in part because large water systems were costly (Crocken and Masten 2000). Municipalities were more likely to search for new water supplies and better able to finance the projects. Therefore an increase in the percentage of the population served by municipalities could signal that greater portions of the population were consuming and benefiting, either directly or indirectly, from expanded and improved water supplies.

The first water filters appeared in London in 1839. By 1886 there were 104 acres of water filter and the estimated daily quantity filtered was 157,000,000 gallons of water (Hazen 1903, pgs.258-259). Deaths from typhoid fever from 1885-1991 for different sources of water for London are given below, described by Hazen (1903, pg. 259) as being very low:

Water Used	Deaths from Typhoid Fever
Filtered Thames water only	125
Filtered Lea water only	167
Thames and Lea jointly	138
Kent wells only	123
Thames and Kent jointly	133

Hardy (1993) suggests the downturn in typhoid mortality beginning in 1870 was spurred, at least in part, by an increase in the quality of drinking water.

The United Kingdom secured their water through a variety of sources including filtered river water supplies, storage reservoirs, and ground water. Hazen (1895) reports that pumping records for the entire year in 1892 shows that the seven companies of London used filtered river water supplies and served a population of over five million with 190 million gallons per day at 38 gallons per head. Birmingham served over 600,000 people and produced 18 million gallons per day from storage reservoirs. London (Kent) secured 16 million gallons of ground water for 460,000 people. While increasing numbers of cities were filtering their water, not all were following suit. Manchester, Sheffield, and Glasgow used unfiltered surface water supplies from storage reservoirs and their prime water sources.

The water dummy variable will take on a value of 1 beginning in 1880 and each decade thereafter, reflecting the decades in which application of water filtration techniques and the evolution of water systems would have been most likely to have a positive and significant effect on height.

United States

The first slow sand filtration plant in the United States was built in Richmond, Virginia in 1832. In 1833, the plant had 295 water subscribers. The next United States plant to open was in Elizabeth, N.J., in 1855. There were only 136 waterworks operating in the United States. After the Civil War, water works construction increased in both countries, but it would be years before their attempts to secure pure water was successful.

The 1880s and 1890s brought improvements in rapid sand filters, slow sand filters, and the first applications of chlorine and ozone for disinfection. In 1897, a movement toward the use of standardization of bacteriological testing was used in laboratories, allowing for the comparison of water purity test results. While significant advancements were being made to understand the complexities of procuring pure water, they were not being implemented at the same pace.

According to Baker, Albany was typical of many American cities in that they ignored the need for pure water for many years and continued to use water from polluted sources. Charles Chandler deemed the Hudson a pure water source in 1872 and his analysis rested on the results from one water sample. The Albany Institute reported that eight miles from Albany large amounts of sewage and industrial wastes were being dumped in the river and predicted significant health consequences for the people of Albany if they were to consume the water. After much fanfare, the city council approved the use of filters in 1872 but no progress would be made towards a securing a purer water supply until 1899. This was the result of scientific and public disagreement on what was to be done and how much it would cost. Allen Hazen was appointed chief engineer in filtration works and the plant was put into use beginning in 1899. In 1900, Hazen reported a bacterial efficiency of 99 percent had been attained and decreased levels of suspended matter and turbidity.

The Hudson continued to improve in the first decade of the 1900s. The typhoid death rate per 100,000 dropped from 171 in 1888 to 0 in 1926. For 1896-1900, the typhoid death rate was 83.8 and dropped to 21.8 from 1902-1905 and fell steadily, with one exception, after that. Baker estimates that in the nine years following the

implementation of filtration techniques, typhoid cases decreased 66.8 percent and typhoid deaths dropped 70 percent compared with the previous nine years.

New Orleans had the most rudimentary water systems of any large city in the United States. For cities with populations greater than 300,00 people, there were 1.342 water mains per 1,000 persons in 1907, while New Orleans had 0.502 mile of main per person (Troesken 2004). Between 1905 and 1915, the city rapidly expanded their water mains and there was a significant reduction in typhoid death rates after 1905 (Troesken, pg. 25). Similarly, improved water filtration met with declining typhoid death rates in Philadelphia in 1908 (Troesken, pg. 27). Troesken suggests that typhoid fever was primarily spread through contaminated water and that the improved water supply significantly contributed to the decline in typhoid death rates.

Joel Tarr (1996) estimated that in 1890, 22.5 million people were connected to public water lines in the United States and Troesken (pg. 40) estimates that between 83 and 99 percent of the urban population were connected to sewer lines in 1910. Troesken also notes that the probability of living in a city with an incomplete water or sewage system fell as city size grew.

According to the Canadian Chlorine Chemistry Council, typhoid fever, cholera, dysentery, and hepatitis A ceased to be public health threats by 1950 and they attribute this to the use of chlorine in water. Chlorine is a disinfectant and was used in water treatment in the early 1900s. In fact, Chicago and Jersey City in the United States began treating drinking water in 1908.

The water dummy variable for the United States will take on a value of 1 beginning in 1900 and each decade thereafter, reflecting the decades in which application

of water filtration techniques and the evolution of water systems would have been most likely to have a positive and significant effect on height.

Belgium

According to Varone and Aubin (2002), from 1804 to 1893 there was some policy focus on protecting the miner water spring of Spa, but rivers were polluted with particles and heavy metals. The building of water distribution networks did not begin until 1893. Hazen reported in 1895 that the raw water in Antwerp was treated by metallic iron in Anderson revolver purifiers and is subsequently filtered at a low average rate and the resulting water quality was described as satisfactory. Anderson's process uses metallic iron for water purification with filters. As the water reacts with the metallic iron to remove harmful material from the water, the filter finishes the job. Hazen (1895) does note that the process probably works better on a small scale. As early as the first half of the 20th century, the low quality of water provisions and its danger to public health became recognized. Since height data is only available until 1880, the water dummy variable for Belgium will take on a value of 0 for each decade.

Germany

The German government set forth rules pertaining to the filtration of surface-water used for public water supplies in 1894. Robert Koch, Nobel Laureate in Medicine in 1905 and one of the founders of bacteriology, sat on the rules committee. The committee created 17 articles, 16 of which were issued to all German local authorities (Hazen 1903). All water-works using surface-water were expected to use them. Below is a summary of select articles:

- The operation of a filter is to be regarded as satisfactory when the filtrate contains the smallest possible number of bacteria and the filtrate must be as clear as possible.
- The filtrate from each single filter must be examined daily.
- A standardized practice for bacterial examination so that results from different sites can be easily compared.
- The bacterial examiner must, whenever possible, be a regular employee of the water-works and show proof he possesses the necessary skills to complete the task.
- When the effluent from a filter does not correspond to the hygienic requirements it must not be used.
- Every single filter shall be independently regulated and the velocity of filtration in each single filter should be capable of being arranged to give the most favorable results.
- A minimum thickness of the sand layer was established.
- Quarterly reports were required of every city using sand-filtered water.

Berlin, with a population of over 1.7 million, had only 161 deaths from typhoid fever in 1893. This translates into only 9 per 100,000 living, one of the lowest rates in comparison to other large European countries (Hazen 1903). Berlin filtered water from the Havel and Spree rivers and in 1898 filtered over 36 million gallons of water per day using a sand filter. Hazen (1895) estimates that Berlin supplied over 1.5 million people with filtered river water. This translates into approximately 16 gallons per person per

day. Munich supplied 300,000 people with ground water from springs, or close to 38 gallons per person per day.

The water dummy variable for Germany will take on a value of 1 in 1890 and zero for each decade prior to 1890. Height data was available only until 1890.

Sweden

Arsta Bay was the main source of drinking water and the increased pollution of the bay in the mid nineteenth century more than likely contributed to the cholera epidemics of 1834 and 1853. After the cholera outbreaks in Stockholm and Gothenburg, better infrastructure was demanded to provide quality water sources as a public health service. After this point, urban areas had access to increasingly pure water supplies. The Public Health Act of 1874 marked a time of declining death rates began and favorable demographic changes. Sweden established and expanded their water and sewerage services in 1890 as municipal departments.

By 1851, it was suggested that water and wastewater services would decrease water-borne diseases, and as a result, a water intake facility was built by Arsta Bay in 1858 (Juuti and Katko 2006). The waterworks and pipe system in Arsta Bay served Stockholm until 1896. Sand filters were used in Arsta Bay and the unfiltered lake water was described as: “muddy, deeply colored yellow, with a large amount of infusorians and an unpleasant odor (Juuti and Katko 2006).” In 1895, sand filters produced 6.5 million gallons of water per day and by 1897, the number had risen to 7.5 million gallons of water per day (Hazen 1903). In 1883 the installation of water closets increased the

pollution of water sources and at the end of the century Arsta Bay was heavily polluted and a new waterworks site was proposed. Drinking water improved when a new water source was constructed, Norsborg waterworks. It began supplying water in 1904 and secured a water supply for the next 100 years (Juuti and Katko 2006).

The water dummy variable will take on a value of 1 beginning in 1890 and each decade thereafter, reflecting the decades in which the procurement of water supplies and application of sand filters would have been most likely to have a positive and significant effect on height.

Netherlands

Urban water supply began to increase in 1854. Initially private water companies were the main water suppliers, but municipalities slowly began to take over water-works as the century progressed. Beginning in 1900 sewerage networks were developed and in some places, such as Rotterdam and Maastricht, modern sewerage systems were in place in the nineteenth century (Hazen 1903).

Cholera outbreaks hit parts of Rotterdam in 1848 and 1866. As a result, the city began to improve their canals with the inception of the 1854 Water Project. The project was a partial success, but public health concerns lingered. Organization problems prevented the city from benefiting from various sanitation proposals and it was not until the typhoid outbreak of 1903 that the problems were addressed. A report from the municipal health board blamed the division of power among too many parties for the outbreak and administrative changes were made following the report. By the turn of the

century, there was a 70 percent connection rate for drinking water supply in South Holland (Juuti and Katko 2006).¹⁵

According to Baker (1981), the water was filtered using double filtration in Holland, first through coarse sand and gravel, then through fine sand. Hazen (1903) reports that the raw water in Rotterdam was originally processed by filters with wooden under-drains. Later the filters were made without the wooden under-drains and following the change he writes that the filters were large, in working order, and well managed with ample preliminary sedimentation.

Sand filters were also used in Amsterdam. Hazen's report estimates that in 1897, the Amsterdam River supplied almost 4.5 million gallons of water per day and the dunes in Amsterdam supplied almost 4.75 million gallons of water per day. Hazen describes Amsterdam's water supplies as originating from canals from the fine dune-sand and the water is filtered after it is collected. In Rotterdam, over 13 million gallons of water were filtered each day. The following cities also used sand filterers in 1893: The Hague, Schiedam, Utrecht, Groningen, Dordrecht, Leeuwarden, Vlaardingen, Sliedrecht, Gorinchem, Zutphen, Leyden, Enschede, and Middelburg (Hazen 1903).

The water dummy variable will take on a value of 1 beginning in 1900 and each decade thereafter, reflecting the decades in which the improved organization of water authorities and application of sand filters would have been most likely to have a positive and significant effect on height.

¹⁵ This was mainly concentrated in urban areas.

Denmark

Water quality became a concern following Chadwick's 1842 report. Since approximately 20 percent of Denmark's population lived in Copenhagen, the city will be used as a point of reference for the development of water quality in Denmark.¹⁶

Copenhagen's first response was to design a competition to select the best new water supply, sewerage, and gas systems proposals. The winning sewage proposal in 1851 suggested that the sea would receive the contaminated water, not the local canals or harbors. The sewage would travel through underground sewers and water closets. In sum, the plan was essentially a redirection of the sewage outside of the city. While the plan won the competition, controversy surrounding the plan delayed its implementation and a cholera epidemic hit Copenhagen in 1853. The cholera epidemic was not enough to convince the city to adopt the visionary design and in its place, the city adopted a new water pipe system in 1856 and what engineers refer to as an 'incomplete' sewerage system in 1860 (Lindegaard 2001).¹⁷

Water closets were being installed more frequently as the 1880s approached. Soon after, the harbors and canals began to smell as human waste began to build. As a result, engineers suggested the waste should be pumped in the sea since it could purify itself naturally. The ocean became the dumping site of Copenhagen's unpurified waste at the turn of the century and the water inside the city was considered safe. It was not until 1930 that Copenhagen changed their practices. Danish newspapers from the northern

¹⁶ In fact, 19 out of 100 births in Denmark were in Copenhagen as of 1900.
<http://64.233.161.104/search?q=cache:C6K9mKlmHQgJ:www.greatestcities.com/Europe/Denmark.html+nineteenth+century+population+copenhagen,+denmark&hl=en&gl=us&ct=clnk&cd=7>

¹⁷ Incomplete refers to the fact that men were still handling human waste.

part of the country reported organized protests against the pollution generated by Copenhagen, claiming their sewage was polluting their coastline (Lindegard 2001).

Outside of sewage systems, sand filters were used to improve water quality. Hazen estimates that Copenhagen filtered over 7 million gallons per day in 1897. The decade 1900 was chosen to reflect the decade in which sewage was carried away from the city and the use of sand filters purified water for a large segment of the principal city, thereby improving local water quality and positively affecting stature.

Below is a table summarizing the decades selected for individual countries.

Table 3.5
Water Dummy Variable

Decade	Belgium	Denmark	France	Germany	Netherlands	Sweden	UK	US
1800	0	0	0		0	0	0	0
1810	0	0	0		0	0	0	0
1820	0	0	0		0	0	0	0
1830	0	0	0		0	0	0	0
1840	0	0	0		0	0	0	0
1850	0	0	0	0	0	0	0	0
1860	0	0	0	0	0	0	0	0
1870	0	0	0	0	0	0	0	0
1880	0	0	0	0	0	0	1	0
1890	0	0	1	1	0	1	1	0
1900	1	1	1		1	1	1	1
1910			1		1	1	1	1
1920			1		1	1	1	1

Notes: Each country was given a 1 for the decade in which it was estimated that their water supply improved such that stature would be positively affected. Height data was not available after 1900 for Belgium or Denmark, and prior to 1850 or after 1890 for Germany.