

ABSTRACT

TREME, JULIANNE. Stature, Nutrition, Health, and Economic Growth. (Under the direction of Lee A. Craig.)

Historically, scholars of economic growth have focused almost exclusively on aggregate output or income as a way to assess the standard of living in a society. This dissertation supplements and challenges this methodology by using evidence of the biological standard of living to measure the physiological adjustments of human populations to changes in economic conditions. Human stature captures the biological costs and benefits of economic activity, and as such, it serves as a primary indicator of the biological standard of living.

When approximated by output and income alone, the standard of living appears to steadily improve over time. Human stature offers a different picture though, fluctuating through time even as incomes rise, implying that the general increase of incomes came at the expense of health, nutrition, and ultimately height. The divergence between economic and biological indicators reveals the importance of representing economies both by material and physical measures-- a reflection of both purchasing power and health.

This dissertation employs stature to approximate income and estimate the health effects of economic fluctuations. It begins by using an innovative estimation technique to generate per capita GDP figures for Colonial America. I identify several undocumented growth episodes. The results of this chapter suggest that early growth rates were higher than previous estimates indicate.

I then shift focus to the regional growth pattern of stature over the nineteenth-century United States, exploring changes in human welfare associated with the convergence of stature, as reflected by the gap between short and tall populations. The results suggest that human welfare did not improve for large segments of the population until the last two decades of the century, and

in fact, the physical costs associated with economic activity overwhelmed the physical benefits for much of the century. The United States experienced a period of divergence in heights across regions, before stature began to converge at the end of the century.

I conclude the dissertation with the global exploration of the impact of economic and health variables on stature in the nineteenth century, finding that Gross Domestic Product and urbanization effects varied across countries. GDP and height were actually negatively correlated in several countries, implying either that GDP increases were spent in large part on unhealthy purchases, or that the negative externalities of growth overwhelmed the positive ones.

STATURE, NUTRITION, HEALTH, AND ECONOMIC GROWTH

by

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Dedication

This dissertation is dedicated to my parents, David and Karen Treme. They passed on their appreciation of education, the desire to work hard, and a belief in God's love in all circumstances. Their example kept me working when I wanted to give up. I am grateful for their encouragement and patience.

Biography

Julianne Treme was born in Georgetown, SC on October 29, 1979 to David and Karen Treme. While attending Salisbury High School, she was the North Carolina High School Athletic Association Individual State Tennis Singles Champion from 1993 to 1996. Julianne attended Elon University, was awarded the A.L. Hook award for the female athlete with the highest GPA in 2000 and 2001, and selected as a second team Academic All-American for tennis in 2001. She graduated with a Bachelor's of Arts degree in Economics in May of 2001 and was the recipient of the John W. Barney Award for the Senior Student with the highest cumulative Grade Point Average. In the fall of 2001 she received the Andrews fellowship for graduate study at North Carolina State University. Julianne married Pete VanGraafeiland on June 18, 2005 in Elon, NC and is currently employed by Wake Forest University.

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1. Introduction

A steady rise in gross domestic product would formerly have been described in terms of an unambiguous rise in living standards. However, the study of living standards is no longer limited to GDP. Human stature captures the biological costs and benefits of economic activity, and as such, stature serves as a primary indicator of the biological standard of living (Steckel 1995). Several country-level studies have identified height puzzles, or periods of simultaneous economic growth and human stature declines, implying that the general rise of incomes came at the expense of both health and nutrition and ultimately height. The divergence between economic and biological indicators reveals the importance of representing economies both by material and physical measures: a reflection of both purchasing power and health.

My dissertation uses stature as an instrument to approximate income and estimate the biological costs and benefits associated with economic fluctuations. In Chapter Two, I employ an original estimation technique to generate growth rates of per capita GDP and identify several undocumented growth episodes in the first half of the eighteenth century United States. Chapter Three focuses on the regional growth pattern of height in the United States over the course of the nineteenth century, exploring the welfare implications associated with the convergence of height as reflected by the gap between short and tall populations. Chapter Four seeks to make a global statement regarding the impact of economic and health variables on stature in the nineteenth-century United States as well as parts of Europe. Finally, Chapter Five concludes the dissertation with a summary and ideas for future research.

Chapter Two presents estimates of American economic growth over the first half of the eighteenth century. While “censuses” were taken in Virginia as early as the 1600s, the first U.S.

census was in 1790, and the scope and content of the questions did not provide enough information to confidently assess economic growth prior to 1840.¹ Although Simon Kuznets and Robert Gallman extended GNP estimates back to 1834 using 1840 census data, there is no universally accepted set of income figures before 1834.

This chapter strengthens interpretations of the patterns and growth rates of GDP in the first half of the eighteenth century. Several researchers have placed economic growth in the range of 0.3 to 0.6 percent per year in the eighteenth century, but these estimates have not gone unchallenged. For instance, George Rogers Taylor (1964) has placed the annual per capita growth estimate as high as one percent; while Mancall and Weiss (1999) present evidence of a per capita growth rate closer to zero. The lack of quantity and quality of data makes it especially difficult to definitively refute any one set of estimates. In the face of incomplete data, researchers, of necessity, will be challenged to find innovative ways to address data limitations. Armed with abundant height data, Chapter Two rises to the occasion, employing a unique estimation technique to produce income figures in a time period where few exist.

The technique overcomes the difficulties resulting from a lack of data by using height data to estimate protein measures in colonial America. Following Craig and Weiss (1998), I model height as a function of nutrition, where nutrition is the marketable protein surplus per person. The net protein measure was computed from a matrix of farm output for each county in the United States in 1840. Mean requirements for humans and animals were subtracted to obtain farm “surpluses”. A positive value indicates residents had access to a plentiful diet and could market the surpluses; a negative value indicates residents were not able to meet basic food requirements. Using eighteenth-century height data, the approach uses empirical results reported in Haines et al. (2003) to estimate aggregate protein output. The protein estimates are then

¹ Since the 1840 census was the first to survey agriculture, and agriculture comprised such a large part of the economy at this time, census data before this year cannot be used to obtain accurate output estimates.

assigned a dollar value based on prices of representative crop portfolios, which are then converted to an estimate of GDP.

While the knowledge of the protein values is useful, how they were divided among different types of food is an important question. Egnal (1998) uses a widow's allotment, or an allotment providing most widows with a reasonable level of subsistence, as a benchmark to describe how average income was spent in 1774. Since the data in this chapter are taken from military recruits, it is necessary to transform the widow's allotment to reflect a male's allotment. Following Lemon (1968), for a family of five, a man's share is 1.5 that of a widow's share. I calculate the market value of the protein in the colonist's diet from the foods in the male's allotment, including wheat, pork, beef, and rye.

After apportioning the protein units among the select foods and adjusting the marketable protein values to reflect values for the entire population, the monetary value was derived from the average annual wholesale prices of wheat, pork, and beef in Philadelphia as reported in colonial and pre-federal statistics from census data.² Using varying estimates of the percentage of income spent on food, a final estimate of GDP was calculated.

My findings suggest that GDP rises until 1724, reaches a nadir in 1730, and rebounds until 1750. GDP estimates for the 1700-1720 time period range from \$850 to \$1,000 (in 1990 dollars) and coincide, roughly, with several existing estimates, including that of Jones, McCusker and Menard, and Mancall and Weiss. The 1740 to 1749 time period suggests an income level very similar to estimates in 1776, implying little or no growth over this time period. In fact, from 1750-1770, Mancall and Weiss report a decrease in the growth rate of 0.02 percent per year. The Mancall and Weiss results estimate the growth rate for the entire century to be 0.04 percent per year and 0.06 percent per year for the first half of the century.

² See United States Bureau of the Census (1970, Series Z 337-356). Prices for rye are from Brooke Hunter (2006).

Results from this chapter present evidence of a much higher average annual rate of change of approximately 1.2 percent per year over the first half of the century. The fluctuations between periods suggest growth swings as high as six percent in certain sub periods. The results uncover new fluctuations in economic activity and offer a more optimistic view of economic growth in colonial times.

The second chapter examines human welfare in the nineteenth century United States. While income steadily rose over the century, height did not follow this unidirectional pattern. Stature rose early in the century, fell mid-century, and rose again at the end of the century. Americans born before 1830 were taller than Americans born in subsequent decades. Specifically, those born in 1830 were more than an inch taller than those born in 1890. Although mean height bottomed out with the birth cohort of 1890, and began rising thereafter, mean height did not reach 1830 levels again until 1920.

The interest in height as an economic variable stems from the work of such economists as Robert Fogel, John Komlos, Richard Steckel, and a host of other researchers. Each saw height's potential to estimate a society's health and standard of living and its ability to reflect the physical costs of economic activity, whether it is by race, social class, or occupation. While a person's genes may determine adult height potential, whether that potential is realized or not depends on the economic and disease environment in which the individual matures (Tanner 1978; Thoday, 1965). Changes in the environment will be the driving force behind changes in average height since genetic differences – i.e. divergence from the mean - approximately cancel in averages across populations. Thus, the comparison of mean adult heights, over time, by state reflects environmental changes, including nutrition, work intensity, and exposure to disease.

As each adult faces a biological height bound, so does each society. There are in fact height limits that no amount of nutrition or medical care can help to surpass. With every

improvement in nutrition, medical care, and technology, a society will take one step closer to achieving an average height equal to its biological bound. Evidence of groups of economies moving towards their biological height bounds will suggest improvements in human welfare. One way to assess whether a society is moving towards its biological height bound is to test for the presence of convergence, or whether initially shorter populations have higher growth rates than those experienced by taller populations.³ Using a data set consisting of mean adult stature for native-born white males in ten-year intervals from 1800 to 1900, the analysis tests for convergence (Barro 1991) of heights among states.⁴

I find that during the period of declining mean stature, heights actually diverged as the height gap between the short and tall populations increased. Evidence from British consumers in Clark et al. (1995) suggests the divergence can be attributed in part to diet differences between urban and rural areas. Rural areas would have consumed more nutrient-rich foods that were higher in protein, such as grains, milk and cheese. In contrast, urban diets were high in caloric quantity - including sugar and alcohol - but less likely to be the type of nutrients necessary to fuel growth. This was a consequence of the nutrient source shifting away from fresh meat and dairy produced and consumed on the farm and towards processed foods and beverages in urban areas. The lack of quality nutrients and protein would have diminished net nutritional status and slowed or even stunted growth in urban areas.

Later in the century we find a type of “negative” convergence, indicating that stature among states tended to converge to a new, lower steady state. A regional difference was identified, as Southern states were declining at a faster rate than either Northern or Midwestern

³ As improvements in environment, medical care, and nutrition become available to broader segments of society, the growth rate of stature would be lower for the taller populations, as they are closer to their biological bound than the shorter populations.

⁴ The base data are from Craig and Weiss (1998) and Haines, Craig, and Weiss (2003) and consist of a sample of Union Army recruits from data originally collected by Fogel, Engerman et al. (ICPSR).

states. As the century progressed, Southern production shifted to cotton and commercial interests at the expense of food crops. As the agricultural sector grew more slowly than the economy as a whole, the point of food and beverage production began to move further from urban cores, and costs to obtain these goods increased. It is possible that the period of “negative” convergence was one showing the decline of southern self-sufficiency manifesting itself through reductions in the growth rate of stature.

The rise of the coal industry—a proxy for industrialization—also contributed to the pattern. The coal industry witnessed remarkable growth in the last quarter of the nineteenth century. But the coal industry boom was accompanied by a host of negative externalities. Working-class men suffered from consistent smoke inhalation and had the highest death rates from acute respiratory disease (Gugliotta 2000). Among the poorest segment of society, increased environmental disamenities and its associated diseases would have negatively influenced the body’s ability to relegate nutrients for growth. The negative health externalities generated by increased coal production were found to significantly and negatively hinder the growth process, and they contributed to the decline in mean height after the Civil War.

Only towards the end of the century do we find classic convergence behavior. After controlling for geographic location, initially shorter states grew faster than initially taller states. In other words, groups of economies began to move toward their biological height bound. The onset of the germ theory of disease and improved living conditions played a major role in improving average height as the body had less demands placed on it by disease and poor environmental surroundings and more nutrients were available for growth. Eventually society’s mastery of the germ theory, and the various manifestations of this mastery in the form of clean public water supplies and sewer systems among other things, overcame the negative externalities associated with industrialization.

Chapter Three succeeds in highlighting stages of the human welfare development path by focusing on the changing magnitude of height differences between short and tall populations. The development path in the present study identifies three periods of development in the U.S. economy as it relates to height: divergence, negative convergence and ultimately positive convergence.

Chapter Four expands the focus from height in the United States economy to height in the global economy. 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. This chapter uses death rates, GDP, urbanization, water supply quality, coal production and railway mileage to study the evolution of height in a cross-section of countries from 1800 to 1920.

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. I construct a global water supply variable, which is the first of its kind, and I use it to test whether securing healthy water supplies significantly affected height. As suggested by the germ theory, it was positive and significant, suggesting that securing healthy water supplies decreased the incidence of disease, specifically typhoid and cholera, and allowed the body to use nutrients for growth instead of fighting infection. As expected, the results suggest that death rates were consistently and negatively related to stature. Coal production significantly and positively affected stature, evidently serving as a proxy for economic growth and overwhelming the negative externalities generally thought to accompany the practice. There was some evidence transportation negatively affected stature.

Urbanization effects varied by country. The negative stature effects were more severe in the United Kingdom, Netherlands, United States, and France. The physical costs generally associated with increased levels of urbanization were not present in the remaining countries. The

GDP effect varied by country and was most beneficial in the Netherlands, the United Kingdom, and Sweden, while the remaining countries appeared to benefit the least from GDP increases. In fact, GDP and height were negatively correlated in the remaining countries. 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, GDP increases had greater stature benefits in other countries.

Overall, the nineteenth century was marked by the spread of industrialization. Economies wholly dependent on agricultural output transformed into economies reliant on heavy machinery and transportation improvements. As concerns over typhoid and cholera outbreaks gradually entered the public conscience, the end of the century saw great improvements in public health, medical research, and technology. Overall, it seems height broadly affected and reflected a common set of factors. However, the results suggest urbanization and GDP effects were not the same across countries and the global coefficients offer a broader picture of what affected height over the period 1800-1920.

2. Chapter 2: Nutrition, Stature, and Economic Growth in the 18th Century

2.1 Introduction

Height can be used not only to supplement income data, but to approximate it as well. The need to approximate income estimates stems from the fact that the 1840 census was the first to survey agriculture. Since agriculture comprised such a large part of the economy at the time, census data before this year cannot be used to obtain accurate GNP estimates, and without agriculture the early GNP figures are based on much guesswork. While Simon Kuznets and Robert Gallman extended GNP estimates back to 1834 using 1840 census data, there is no universally accepted set of income figures before 1834.

I employ a unique income estimation technique to generate per capita GDP estimates for the first half of the eighteenth century. Using height data, I estimate total protein, in grams per person, and calculate and apportion them among frequently consumed foods. Their dollar value yields a variation of GDP. Previous studies have estimated economic growth to be between 0.3 and 0.6 percent per year in the eighteenth century, and one has placed the number closer to zero. The findings in this study identify several growth episodes in the subperiods from 1700-1750 and suggest per capita GDP grew at approximately 1.1 percent per year over the fifty-year period. This higher growth estimate using my technique results from a higher 1750 income estimate as compared to earlier estimates.

2.2 The Difficulties of the Census

The first U.S. census following the Constitution's ratification was taken in 1790 and mainly surveyed population characteristics.⁵ The records for the first census are incomplete because a fire, during the War of 1812, destroyed data for five states. Furthermore, the accuracy is highly questionable as lists were posted at taverns of public places so persons overlooked could insert their name (Wright 1943). The difficulties to completing the census were immense. The first census took 18 months to complete because of poor roads, virtually non-existent bridges, hostile natives, limited transportation options, and undefined boundaries. The Old Testament even contributed to the census difficulties. The colonials were well aware of the sickness that befell the Israelites when King David ordered a census against God's will and were reluctant to participate in a census of any variety. Finally, the population resisted providing data because they were afraid the census would result in higher taxes.

Contemporary census techniques are the result of an impressive evolution of the census's scope and accuracy. Unfortunately, the early years of the census suffered from unsophisticated statistical techniques and a limited range of questions. While census data prior to 1840 cannot be reliably used to derive income estimates prior to 1834 this has not prevented economists from proposing other methods to estimate the pattern of per capita income in the early American economy.

2.3 Income Estimates Prior to 1770

The lack of reliable census data has forced economists to explore other avenues of estimation and each has postulated their own theory as to the pattern of economic growth prior to

⁵ The United States was the first among nations to make a Constitutional or legal provision for a regular enumeration of its inhabitants.

1770. If it was difficult to garner income estimates from census data in the early nineteenth century, using census data to infer growth patterns prior to 1770 presents an even bigger challenge.

Robert Lucas (2002) estimated per capita income to be approximately \$729 in 1990 U.S. dollars from 1750-1800. Prior to 1750 he asserts income differences across regions were minimal in comparison to those across contemporary populations, and he argues living standards before 1750 changed slowly. The assumption of similar living standards and lack of income inequality allow him to apply the \$600 income per capita estimate to all societies preceding 1750, an assumption to which historians take exception.

George Rogers Taylor (1964) uses Raymond W. Goldsmith's testimony before the Joint Economic Committee to present an estimate of U.S. per capita income prior to 1839. Goldsmith (1959) estimated the rate of economic growth to be just under 2 percent per year over the 1839-1959 time period. Applying the same rate of growth to the previous century generates a per capita income estimate of approximately \$939 in 1710, in 1990 dollars. Goldsmith argues that the estimate is too low given the living standards of the colonists at the time and concludes that the rate of growth must have been slower than that observed in the 1830-1959 time period. He questions whether the average growth rate exceeded 1 percent in any 50-year period prior to 1839. Goldsmith's per capita income estimate is widely used as a lower bound in the range of colonial per capita income estimates. Taylor speculates that the average growth rate was approximately 1 percent per capita from 1710-1775, stemming from the increased role of tobacco, rice, and indigo on southern plantations, growth in population, and expansion of settlement.

Robert Gallman (1972) uses Goldsmith's \$939 estimate as a lower bound to the colonist's per capita income in 1710 and suggests that the figure would have only covered food and fuel consumption in the mid-nineteenth century. Since the colonists were known to purchase

goods other than food and housing, the estimate can be considered a low-end benchmark for which estimates below this are doubtful. He places an upper bound on per capita income at \$1172, or the level of English per capita income in 1720.

Angus Maddison (2001) estimates U.S. per capita income in 1710 to be \$527 in 1990 “international” dollars. Maddison uses Goldsmith’s starting point, assuming average per capita income in 1839 was \$400 (in 1959 dollars). Maddison estimates agricultural productivity growth to be 0.62 percent a year from 1820 to 1840 and assumes the rest of the economy experienced productivity growth of one percent per year.⁶ Thus, Maddison assumes overall growth in the economy from 1820-1840 is roughly 1.62 percent annually. Gallman estimated the per capita growth in net national product to be 0.42 percent a year between 1710 and 1840. Maddison (1995) adjusts Gallman’s estimate to reflect the faster rate of growth between 1820 and 1840 and proposes that per capita income in 1700 was roughly \$909 in 1990 international dollars.⁷

To arrive at his final estimate of \$527, he makes a distinction between the make-up of the population. The \$909 estimate only applies to the non-indigenous population⁸, which accounted for only 25 percent of the total population in 1700. Maddison assumes the indigenous population had a per capita income of \$400 in 1700, where \$400 is the assumed subsistence level of income in this time. Combining the indigenous and non-indigenous populations, he finds average per capita income for the population to be \$527 in 1700.

Alice Jones (1980) uses wealth to approximate per capita income. Once wealth is estimated, in part by using probate inventories and a “plausible guess”, she assumes a 3.5 to 3.0 to 1 ratio of wealth to income. After using the ratio, she estimates per capita income grew at around 0.4 percent per year from 1700-1840. Translated into 1990 dollars and using Jones’s

⁶ He uses evidence from Towne and Rasmussen (1960), Kuznets (1952) and David (1967).

⁷ If the growth rate was 1.62 percent per year from 1820-1840, then take $400(1-.0162)^{20}=288$ in 1959 dollars, which is roughly what Maddison estimated. To arrive at income in 1700, take $288*(1-.0029)^{120}=203$, which again is roughly what Maddison estimated from 1700. The 1710 estimate would be \$941 in 1990 dollars and the 1720 would be approximately \$965 in 1990 dollars.

⁸ This includes only black and white populations.

suggested ratio of wealth to income, her figures suggest per capita income estimates in 1700 ranging from \$868 to \$1015.

McCusker and Menard (1985) infer an annual growth rate ranging from 0.3 to 0.6 per capita between 1690 and 1785. The authors arrived at the range by observing Britain's economic growth. The lower bound is Britain's annual average per capita growth rate of 0.3 percent between 1690 and 1785. Since the United States started behind Britain in terms of growth, McCusker and Menard allow for the fact that the United States could have grown faster than Britain and set the upper bound at 0.6 percent. While the rate may seem low, it would be enough to double income over the period in question. Using Alice Jones's estimates of 1774 income per capita, McCusker and Menard extrapolate backwards using their proposed set of growth rates. The growth rates translate into a per capita income estimate range from \$918 to \$1081 in 1720 (in 1990 dollars).

Mancall and Weiss's (1999) conclusions diverge from the consensus of growth rates ranging from 0.3 and 0.6 percent per year. In fact, they suggest economic growth was closer to zero. The authors estimate the "most likely course of economic growth" and propose that per capita income grew at 0.04 percent per year for colonists and their slaves between 1700 and 1800. Using David's (1967) and Weiss's (1992) estimates of 1800 per capita income, Mancall and Weiss's growth rate implies a per capita income range of \$841 to \$946 in 1700.

Mancall and Weiss estimate GDP in the following equation as a function of food produced and consumed within the colonies (f), firewood (w), agricultural products that were exported (x_a), rental value of dwellings (h), and a broad category for nonagricultural output including the value of manufactured goods, investment, and services.

$$\text{GDP} = f+w+x_a+h+n$$

Their GDP estimate does not include value of farm improvements or home manufacturing.

Mancall and Weiss then take the values of each of these variables in 1800 from existing work and extrapolate backwards to achieve early eighteenth century output estimates. The scarcity of data forced them to make several assumptions. Production of food is assumed to be closely approximated by consumption, while food consumption per person and dwelling share of wealth and of structures is assumed to be constant over time. The proportion of non-agricultural workers is assumed to be roughly 8 percent of the total population. Their results indicate the export sector pulled down the rate of economic growth of early colonial America. While real agricultural exports in the aggregate increase, they evidently did not increase at the rate of population growth.

Menard (2006) describes Mancall and Weiss's assumptions as "heroic" and suggests their assumptions ignore existing literature. While Mancall and Weiss assume that per capita value of American food consumption was constant over the colonial period, Sarah McMahon's work (1994) suggests there were substantial improvements in the colonial diet. Where Mancall and Weiss assume colonial housing was a constant proportion of income over the 1700 to 1800 time period, several economists have shown that the colonist's budget for housing varied by time, class, and region (Bushman 1992).

To summarize, Table 1 displays the array of per capita income estimates and for ease of comparison all values are in 1990 dollars. All but Mancall and Weiss's estimates are the products of speculation of one degree or another, much of it using known growth rates or wealth figures from Britain and applying those to U.S. data. The lack of quality data required Mancall and Weiss to employ their conjectural method. To generate estimates, they used what Menard also describes as "back of the envelope" calculations. But in the face of incomplete and unknown data, researchers will be challenged to find ways around data limitations; Mancall and Weiss's attempt merges available data with extrapolations and their efforts should be commended, as their estimate can only be compared to the more speculative per capita income estimates of others.

2.4 Overview

The first U.S. census after the American Revolution was taken in 1790, but other censuses were taken as early as the 1600s. Unfortunately, the scope and content of the questions did not provide enough information to confidently assess economic growth. Early GDP estimates are important if only to strengthen interpretations of early growth and the patterns of GDP after 1840. The primitive nature of early census data call for a different approach to produce income figures in a time period where few estimates exist.

Previous studies have generally estimated GDP for the years 1700, 1750, and 1770. The years in between have remained a mystery. This study seeks to strengthen interpretations of the patterns of GDP growth in the first half of the eighteenth century. In contrast to current and prior research, the approach taken here allows GDP to fluctuate between time periods. GDP can be found for several time periods in the eighteenth century, allowing for the comparison over a fifty year time period. Economic growth is not forced to be constant over decades. For instance, this study does not calculate the growth rate of GDP between 1700 and 1750 and assume it to be constant over the time period to estimate the GDP in 1720. An assumed constant rate of growth misses any economic fluctuations in the economy and thereby neglects activity in between decades.

My findings suggest there is merit to discarding the constant growth assumption and allowing GDP to fluctuate in the first half of the eighteenth century. GDP rises until 1724, reaches a nadir in 1730, and rebounds after this period. While I think the trend in GDP is an accurate assessment of the economy in the first half of the eighteenth century, it was necessary to make several assumptions to arrive at the results.

2.5 Method

Aggregate output is defined as the value of output produced within the United States eighteenth-century economy by native-born, adult, white males in this paper. The estimates here will not have the same accuracy as estimates in later centuries, since the data are limited. While it is true that the shortest distance between two points is a line, when it is impossible to connect the points, one must use alternative methods to construct a new estimate. It is in this light that the reported estimates should be viewed: as an experiment to find a new path to reach eighteenth century output estimates.

Reliable income data do not exist for the early eighteenth century, but height data are readily available. Following Craig and Weiss (1998) and Haines et al. (2003), height is a function of nutrition, where nutrition is the marketable surplus per person of protein. The net protein measure was computed from a matrix of farm output for each county in the United States in 1840 and mean requirements for humans and animals were subtracted to obtain the net surplus figures. A positive value indicates residents had access to a more plentiful diet; a negative value indicates residents were not able to meet basic food requirements. Using height data, the approach will implement the empirical results reported in Haines et al. to estimate protein measures in colonial America. The protein measures will be assigned a dollar value and be converted to an estimate of GDP. In short, I estimate the amount of output necessary to produce the stature of the native-born population, and extrapolate this information to the rest of the economy.

The height data are from a sample of military recruits.⁹ The original data set included 16,545 recruits which were then narrowed to include only native-born, adult, white regiments

⁹ John Komlos supplied these data from his investigations of individual muster rosters from the various wars and militias of the eighteenth and early nineteenth centuries.

with birth date, enlistment date and county, occupation, skin color, and birth county available. This process paired down the observations to 2,894 recruits for the 1700-1749 time period.

Height observations are then applied to the Haines et al. regression results using the following equation:

$$\text{Height}_i = \alpha + \beta_1 \text{Mover}_i + \sum_{t=1700}^{1865} \beta_{2it} \text{Year}_i + \beta_3 \text{Farmer}_i + \beta_4 \text{Laborer}_i + \beta_5 \text{Nutrition}_i + \beta_6 \text{Wealth}_i + \beta_7 \text{Transport}_i + \beta_8 \text{Urban}_i + \beta_9 \text{Hindex}_i + \varepsilon_i \quad (2.1)$$

Where Height_i is the height of the i th recruit. Mover equals one if the recruit enlisted in a county other than he one in which he was born, zero otherwise. Year_{it} is one if the i th recruit enlisted in the t th year, zero otherwise. Farmer and Laborer are one if the recruit was a farmer or laborer, respectively, zero otherwise. Nutrition is the marketable surplus per person of protein in the county in 1840. Hindex is the Herfindahl index of concentration of the source of the nutrients in the country. Wealth is the sum of agricultural and industrial wealth (per capita) in the county in 1850. Transport equals one if the county was on a navigable waterway in 1840, zero otherwise. Urban was the proportion of a county's population residing in an urban area.

Obviously all variables in Equation 2.1 cannot be used. For instance the dummy variable for years from 1862 to 1865 will be discarded. In addition, Urban and Hindex will not be used, as neither is available on county level in the eighteenth century.¹⁰ Eighteenth century data are available on the variables height, mover, farmer, laborer, wealth, and transport.¹¹

Equation 2.1 will be used to obtain estimates of the nutrition variable, or marketable protein surplus per person using regression coefficients from Haines et al. Using the coefficients

¹⁰ In Haines et al. (2003), the variable urban was statistically significant at the 1 percent level, while Hindex had a positive coefficient but was not statistically significant.

¹¹ The nutrition variable is not available and will be estimated using the parameters of the equation. The wealth data is from 1850 and was estimated for the eighteenth century using McCusker (2006).

in equation 6 of Table 7 from Haines et al. and the eighteenth century height, mover, farmer, laborer, wealth and transport data, nutrition estimates can be found by rearranging equation 2.1.¹²

$$\text{Nutrition}_i^{***} = (\text{Height}_i - 68.1624^{***} - 0.1236\text{Mover}_i^* - 0.5194\text{Farmer}_i^{***} - 0.1274\text{Laborer}_i + 0.0009\text{Wealth}_i^{***} + 0.2923\text{Transport}_i^{***}) / 0.1161 \quad (2.2)$$

The regression equation is valuable because it offers an alternative method to obtain protein estimates and subsequently per capita income figures for the eighteenth century. Since the nutrition variable is not available in the eighteenth century, it is not possible to simply use the nutrition variable or run similar regressions and obtain new regression coefficients.¹³ Eighteenth-century regression coefficients will have to be replaced by estimates, specifically the regression coefficients from Haines et al. It is necessary to assume that the estimates do not differ significantly from the true eighteenth century regression coefficients. Since these are biological coefficients, or coefficients from a biological production function, they would not be expected to change much over several generations and the estimation method will proceed using the estimated regression coefficients from Haines et al.¹⁴

Equation 2.2 yields estimates of protein grams per adult equivalent per day. The resulting average protein gram figures for each birth date are shown in Table 2. The average surplus protein production estimates for various time periods are primarily negative, indicating a nutritional deficiency in most time periods, and are significantly lower than the average surplus

¹² *** denotes a variable significant at the 1 percent level.

¹³ Since data for the actual nutrition estimates are not directly obtainable, it is necessary to use the regression coefficients to obtain estimates for the eighteenth century, though it is recognized that the approach may result in nutrition estimates that are inconsistent.

¹⁴ Haines et al. found a positive relationship between nutritional access in infancy and adult height. Protein is used to test the relationship and is measured in hundreds of grams per adult equivalent per day. The results suggest a recruit spending infancy in a county that produced a net protein surplus would be taller than a recruit from a county with a protein deficit.

protein production of 1.5799 grams per day from Haines et al. The negative protein values pose a problem, as they translate into negative GDP values.

While the numbers in Table 2 do not look encouraging on first glance, the reason becomes apparent when looking at the average height for each birth date group in Table 3. Note that in every period the average height is lower than the average height given by Haines et al. of 68.253 inches. This becomes important when using the Haines et al. regression coefficients, specifically the intercept. If every variable in the Haines et al. regression were held constant at a value of zero, height would have a value of 68.1624 inches, or approximately 0.1 of an inch lower than the Haines et al. average height of 68.253 inches. Table 4 shows the difference between the average height for each eighteenth-century time period and the Haines et al. intercept term.

A problem is encountered, as the nineteenth century average height estimates do not closely resemble the eighteenth century average height estimates. The mean differential affects the accuracy of the estimates, resulting in a likely under-estimation of the variable in question. As a result of the realized equation error, an intercept adjustment will be used to improve the performance of the eighteenth century estimates.

Since the intercept is closely approximated by average height, the underestimation can be illustrated by supposing the nineteenth century intercept μ changes to $\mu+\beta$ in the eighteenth century. On average, an error of β would be made if it were not realized that the average height had changed. If the intercept is adjusted to reflect β 's value, then the estimate should more appropriately reflect eighteenth century conditions.¹⁵ For instance, the 1725-1729 period is closest to the Haines et al. intercept. Table 2 estimates the average marketable protein surplus production figure to be 0.77 in this time period, translating into a reasonable GDP per capita

¹⁵ Since the true value of β is not known, an estimate of β will necessarily introduce some error into the estimates, but the error should be smaller than using the original Haines et al. intercept.

estimate of roughly \$1,100, in 1990 dollars. Therefore using an intercept closer to the mean height should generate a more reasonable estimate.

Since there is not an obvious intercept value to assume for every time period, an assumption must be made as to the magnitude of the intercept adjustment. In view of the fact that the time period 1725-1729 produced a reasonable result, the intercept will be approximated using this period as a model for adjustment. Since the difference between average height in the 1725-1729 period and the Haines et al. intercept is 0.11, this value will be added to the average height to adjust the intercept in each eighteenth century time period. The intercept adjustment will be used in all estimates below. Adjusted average marketable protein surplus estimates are shown in Table 5.

While this adjustment is admittedly ad hoc, it is worth keeping three things in mind. First, in principle some adjustment is called for, as a result of the fact that mean stature increased between the period covered by these data and those covered by Haines et al. Secondly, the adjustment has to be in the direction of increasing the intercept, and by choosing the smallest option, in absolute value, in Table 4 I have biased my estimates downward. Finally, in a sense, this exercise is really one in which we are asking: What does one need to do, or how much does one need to “tweak” this technique, to obtain results in the neighborhood of those “back-of-the-envelope” estimates of other scholars.

2.6 Calculations

While the knowledge of the protein surplus is useful, how was this surplus divided among selected foods? In Marc Egnal’s New World Economies, a widow’s allotment, or “the amount of food, clothing, and cash that would allow a single, older woman to live comfortably”,

is used as a benchmark to describe how average income was spent in Pennsylvania in 1774. The widow's allotment in Egnal is shown in Table 6.

The figures are an average of a diverse population, but Egnal notes that the largest population included the middling farmers, and their presence would have substantially influenced the average.¹⁶ Egnal concludes that the average income for colonists in 1774 provided most colonists with a reasonable level of subsistence. Since the data in this paper are taken from recruits, it is necessary to transform the widow's allotment to reflect a male's allotment. The widow's allotment is assumed to approximate the mean for families of five, which was the average size of a family at that time. Following Lemon (1968), for a family of five, a man's share is 1.5 that of a widow's share. Therefore, Table 6 can be converted accordingly to reflect a male's allotment and the result is in Table 7.

The nutrition variable, or marketable surplus of protein, constructed using Haines et al. regression coefficients can be used to determine the dollar value of a colonist's diet. The value of the colonist's diet will be calculated from the most frequently mentioned foods in the male's allotment: wheat, pork, beef, and rye. Since price data for apples are not available, they cannot be used in the computations. These items, minus apples, account for almost 95 percent of the income devoted to food per capita via the male's allotment and therefore should be a good approximation of the dollar value given to the nutrition estimates.

It is not assumed that the grams of protein were equally divided among the selected foods. The quantity for annual subsistence from the male's allotment was used to compute the percentage of protein grams that would have been devoted to each food. The division of protein grams between wheat, pork, beef, and rye is shown in Table 8. For instance, if the marketable surplus of protein for a colonist has a value of 100 grams per person per day, then the last column in Table 8 apportions 56 of these protein grams to wheat, 16 to pork, 9 to beef, and 19 to rye.

¹⁶ Jones (1980) shows the average income in the North was similar to the average income in the South.

The marketable surplus of protein will reflect only the individuals involved in non-agricultural labor since the population involved in agriculture activities would not need to go to the market. McCusker and Menard (1985) estimate that before the American Revolution, 20 percent of the workers were employed in non-farm labor, and they see little reason why the percentage would be much different in previous decades. To obtain protein surplus production for the entire population, it is then necessary to solve a basic algebra equation:

$$(\% \text{ NFLF}) * (\text{Total Protein Surplus for entire population}) = \text{Marketable Surplus of Protein Production} \quad (2.3)$$

Where NFLF is the non-farm labor force. Using McCusker and Menard's estimate for the percentage of non-farm labor force participation and the marketable surplus of protein production in Table 2, it is possible to compute the total protein surplus for the entire population by solving equation 2.3 for the total protein surplus. To obtain the total protein surplus for each food for the entire population, each marketable surplus figure should be divided by 20 percent. The dollar value of protein grams will be assigned to the resulting values.

The monetary value is derived from the average annual wholesale prices of wheat in Philadelphia as reported in colonial and pre-federal statistics from census data.¹⁷ As a British colony, the United States followed the British monetary system and therefore the prices listed are in Pennsylvania shillings. The currency in Pennsylvania included coins of Spanish, Portuguese, French, Dutch, and English origin. The most popular silver coin was the Spanish piece of eight, later known as the Spanish milled dollar. Its popularity led the colony to use it as a basis for rating other coins. Therefore the amount of Pennsylvania currency that was paid for with £100

¹⁷ See the United States Bureau of the Census (1970, Series Z 337-356). Philadelphia prices were used to complement the Widow's Allotment data from Egnal.

sterling in goods and services depended on the value assigned to the Spanish dollar. Bezanson et al. (1951) suggests that during most of the colonial period, the Spanish milled dollar was valued at 7 shillings 6 pence in contrast to the rating of 4 shillings 6 pence in London. The ratio between these valuations would make the exchange rate $166\frac{2}{3}$. The exchange rate was not stable over the colonial era, and the variations over the eighteenth century should be taken into account when using the exchange rate. As a result of the volatility in exchange rates over the relevant time periods, the average monthly rates of exchange on London Pennsylvania currency for £100 sterling were used from 1720-1775.¹⁸

Once the conversion is made from Pennsylvania shillings to pounds sterling, the last step is to convert pounds sterling to U.S. dollars. The conversion is derived from Derks and Smith (2005).¹⁹ They report that in 1786 the British official price of gold per ounce was £4.25 and the United States official price of gold per ounce was \$19.49. Therefore £1 was worth approximately \$4.59 in 1786.²⁰

The price of a bushel of wheat, a pound of pork and beef, and a bushel of rye and their dollar values are given in Tables 9,10,11, and 12. The total protein surplus will be apportioned among the foods listed in the male's allotment, including wheat, pork, beef, and rye. The portion of income devoted to each food will be calculated by multiplying the price times the estimated value of the average marketable surplus of protein generated from the Haines et al. regression coefficients. Column 6 in Table 8 will determine how the protein surplus will be divided among the foods.

Table 13 summarizes the prices of each food in every time period. Since the dollar values for each food are in bushels or barrels, the total protein surplus must be calculated in

¹⁸ See Bezanson et al. (1951, p. 431).

¹⁹ Although the U.S. dollar was not "officially" defined until the coinage act of 1792, it was used as a unit of account before that time.

²⁰ Derks and Smith (2005, p. 159).

bushels or barrels. Therefore, if the total marketable surplus per capita per day of protein from wheat is 280, this translates into almost a tenth of a bushel of wheat, or \$0.05 a day in 1720.²¹ In this way the daily values of average protein grams for the population are transformed into an income estimate.

Table 14 shows the total surplus of protein per day per capita as distributed among wheat, pork, beef, and rye from Equation 2.2. The dollar value of the foods yields a variant of per capita GDP, one I will call gross food product, or GFP. GFP is listed in Table 15. Per capita food product describes the dollar value of the marketable surplus of protein per day as it is divided among certain foods. The variable is relevant because food consumption would have accounted for a large portion of the individual's total income (Komlos 1994).

Combining the per capita GFP estimates with the percentage of income spent on food, as suggested by the male allotment, allows for the estimation of a per capita GDP. While the method is certainly not meant to produce exact income estimates, it can provide a rough measure of overall per capita economic activity.

According to the male allotment, GFP accounted for 48 percent of income. Therefore the current estimate must be divided by 0.48 to generate an annual per capita GDP estimate. It is likely that GFP comprised a higher percentage of average income from 1720 to 1750 than in 1774. In fact, GFP is the dollar value of the total number of protein grams and would therefore capture a higher percentage of income than wheat, pork, beef, and rye alone. As a measure for comparison, it is assumed that GFP accounted for 58 percent of average income. The estimated annual per capita income figures and their value in 1990 dollars is reported in Table 15.

Assuming that the value of food consumed accounted for 48 percent of total income, GDP per capita was just over \$1,000 in 1990 dollars over the period 1700-1720. If the higher

²¹ See Column 6 of Table 11 for the dollar value of a bushel of wheat. The figure assumes a bushel of wheat costs \$0.53 in 1720.

percentage of 58 is assumed, GDP per capita was close to \$850. This range is nearly identical to Jones's estimates for the time and is similar to the per capita income estimates listed in Table 1, including McCusker and Menard. Since the estimates are similar to existing ones over the 1700-1720, there is reason to examine the remaining estimates for later periods.

The 1776 per capita income estimate generally has an upward bound of \$1,374 (Alice Jones), though Goldsmith's 1776 estimate is over \$2,000. McCusker's estimate is \$1275 and Mancall and Weiss's estimate is just under \$1,000.²² The estimates in Table 15 are similar in magnitude and provide support for the fact that the current estimates do not do too much violence to the true estimates. The 1740-1749 time period suggests an income level very similar to estimates in 1776, implying little or no growth over this time period. In fact, from 1750-1770, Mancall and Weiss report a decrease in the growth rate of 0.02 percent per year.

The figures in Table 15 suggest that over the first half of the century, per capita GDP fluctuated significantly. The Mancall and Weiss results suggest GDP per capita rose by only \$3 (in 1840 dollars) over the entire century, and they estimate the growth rate for the entire century to be 0.04 percent per year and 0.06 percent per year for the first half of the century, a growth rate significantly lower than every other existing estimates. Using Columns 4 and 5 from Table 15, the average annual rate of change over the first half of the century is approximately 1.2 percent per year. Table 16 breaks down the per capita growth rates by period.

The result shows a great deal of variation in GDP per capita growth rates in the first half of the century. GDP per capita rises until 1724, reaches a low point in 1730, and rises after this period. The growth rate over the first half of the century was found to exceed 1 percent, which is considerably higher than other estimates. The fluctuations between periods suggest growth swings as high as 6 percent in certain subperiods. Although swings of this magnitude would be large by current standards, they are in line with European business cycles for the eighteenth

²² All estimates are in 1990 dollars.

century (Craig and Fisher (2000); Craig and Garcia-Iglesias (2006)). The results imply that the colonist's standard of living was not steadily rising and uncovers fluctuations in economic activity not previously identified.

2.7 Conclusions

The estimates here suggest that economic activity was quite volatile during the first half of the eighteenth century. When broken into five time periods, several growth episodes were observed from 1700 to 1750. While some episodes appeared to be a response to previous growth, the growth rate over the first half of the eighteenth century appears to be higher than previous estimates.

The method used to generate per capita GDP estimates is quite different than previous research. Using a variation of a widow's allotment, I was able to identify frequently consumed foods. The Haines et al. regression coefficients allowed me to generate an estimate of the total number of protein grams per person. Nutritional data allowed me to assign the percentage of protein grams to each of the frequently consumed foods. In conjunction with existing price data, I was able to formulate the dollar value of the foods listed in the male's allotment and eventually obtain GDP per capita estimates.

The economic fluctuations observed should not be surprising. The colonial era was one of emerging markets and tremendous growth in exports. Furthermore the aggregate economy was dominated by the volatile agricultural sector, and the economic fluctuations are surely reflecting this. Early-modern agricultural economies were subject to fluctuations as a result of climatic fluctuations. While adjacent periods indicate some swings are the result of a significant time of growth or setback, the overall growth rate for the first half of the century indicates growth in per capita GDP in excess of 1 percent per year, which was quite high by earlier standards.

Estimating historical rates of economic growth is not an easy task, evidenced in part by the diverging viewpoints in the literature. The results are interesting in the sense that they reveal significant swings in economic activity. They are valuable because they suggest alternative methods may be necessary to assess the pattern and magnitude of economic growth. While this paper certainly does not settle the issue of whether or not significant economic growth occurred in the eighteenth century, it offers a unique estimation method to address a contentious issue.

Table 2.1

Per Capita Income Estimates

(All estimates are in 1990 dollars)

Year	Per capita Income Estimates	Researcher
1700	\$729	Lucas
1700	\$939	Goldsmith
1700	\$909	Maddison
1700	\$841-\$946	Mancall and Weiss
1710	\$918-\$1081	McCusker and Menard
1710	\$939-\$1172	Gallman
1720	\$868-\$1015	Jones

Notes: Maddison's estimate refers only to non-indigenous populations. Gallman's range reflects the lower bound of Goldsmith's estimate and the upper bound of English per capita income. McCusker and Menard's range is a result of English growth rates varying from 0.3 to 0.6 percent a year between 1690 and 1785. Mancall and Weiss's range uses Weiss's and David's 1800 per capita estimate as a starting point. Jones's estimates are the result of using varying wealth to income ratios.

Table 2.2
Estimated Protein Measures

Birth Date	Average Marketable Protein Surplus Production (100s of grams per adult equivalent per day)	Number of Observations
1700-1719	-0.43	227
1720-1724	-3.54	200
1725-1729	0.78	276
1730-1734	-3.54	595
1735-1739	-0.78	1105
1740-1749	-0.35	491

Table 2.3
Average Height Differential

Birth date	Average Height	Difference (Average height in 18th century – Average height in Haines et al.)
1700-1719	67.92	-0.33
1720-1724	67.55	-0.70
1725-1729	68.05	-0.20
1730-1734	67.61	-0.64
1735-1739	67.90	-0.35
1740-1749	67.93	-0.32

Table 2.4
Average Height Differential: Intercept

Birth date	Average Height	Difference between Average Height and Haines et al. Intercept (68.1624)
1700-1719	67.92	-0.2424
1720-1724	67.55	-0.6124
1725-1729	68.05	-0.1124
1730-1734	67.61	-0.5524
1735-1739	67.90	-0.2624
1740-1749	67.93	-0.2324

Table 2.5

Adjusted Protein Measures

Birth date	Average Height	Average Marketable Protein Surplus Production (100s of grams per adult equivalent per day)
1700-1719	67.92	0.80
1720-1724	67.55	0.86
1725-1729	68.05	0.87
1730-1734	67.61	0.38
1735-1739	67.90	0.66
1740-1749	67.93	0.82

Table 2.6

Widow's Allotment, Pennsylvania, 1774

Item	Quantity for Annual Subsistence	Value
Wheat	13.2 bushels	2.7
Pork	102 lbs.	0.9
Beef	51 lbs.	0.4
Rye	5.4 bushels	0.7
Apples	Unspecified	0.3
Wool	6.0 lbs	0.3
Money		4.5
Total Value		9.8

Notes: Table from Egnal (1998, p. 45).
Values are in pounds sterling.

Table 2.7
Male Allotment, Pennsylvania, 1774

Item	Quantity for Annual Subsistence	Value
Wheat	19.8 bushels	4.05
Pork	153 lbs.	1.35
Beef	76.5 lbs.	0.6
Rye	8.1 bushels	1.05
Apples	Unspecified	0.45
Wool	9 lbs	0.45
Money		6.75
Total Value		14.7

Note: The quantity for annual subsistence is assumed to be 1.5 times that of the widow's allotment in Table 8.

Table 2.8
Apportioned Protein Grams

Item	Quantity for Annual Subsistence	Quantity for Daily Subsistence	Total Number of Protein Grams in a bushel or pound	Percentage of Protein Grams Devoted to each Item
Wheat	19.8 bushels	0.054	2880	0.569
Pork	153 pound	0.419	103	0.157
Beef	76.5 pounds	0.210	112	0.086
Rye	8.1 bushels	0.022	2330	0.188

Notes: Column 3 is Column 2 divided by 365.

Column 4:

Wheat: There are 60 pounds in a bushel of wheat. The number of protein grams in a bushel of wheat is approximated using figures from whole wheat bread in Ensminger Tables, Table P-37. There are approximately 3 grams of protein in one ounce of whole wheat bread, or 48 grams of protein in one pound, or 2,880 grams of protein in a bushel of wheat. It is recognized that different comparisons would yield different values of protein grams in a bushel. The selection of whole wheat bread biases the estimates downward.

Pork: Protein grams from pork are calculated from a cooked shoulder blade of steak in the Ensminger Tables (1994), Table P-37. There are approximately 6.4 grams of protein in one ounce of a cooked shoulder blade steak, or 103 grams of protein in one pound of cooked shoulder blade steak.

Beef: Protein grams from beef are approximated using nutritional data from Ensminger Table P-37 on cooked hamburger. There are approximately 7 grams of protein in one ounce of cooked ground beef, or 112 grams of protein in a pound of cooked ground beef.

Column 5 is calculated by multiplying Column 3 and Column 4 and dividing by the sum of all items in the Widow's allotment.

Table 2.9**Dollar Value of a Bushel of Wheat**

Year	Price of a Bushel of Wheat in Pennsylvania Shillings	Price of a Bushel of Wheat in Pennsylvania Pounds	Exchange Rate on London Pennsylvania Currency for £100 Sterling	Price of a Bushel of Wheat in £ Sterling	Dollar Value of a Bushel of Wheat (£1 Sterling = 4.59 US dollars)
1700-1719	3.08	0.15	133.33	0.12	\$0.53
1720-1724	3.80	0.19	133.33	0.14	\$0.65
1725-1729	3.61	0.18	155.00	0.12	\$0.55
1730-1734	3.09	0.15	160.00	0.10	\$0.44
1735-1739	3.46	0.17	164.50	0.11	\$0.48
1740-1749	3.61	0.18	170.00	0.11	\$0.49

Notes and Sources: The exchange rate from 1700-1719 was assumed to be the same as the exchange rate in 1720. The exchange rates in subsequent time periods are the averages of monthly rates of exchange. See Table 17, page 413 of Bezanson (1951).

Prices of a bushel of wheat in Pennsylvania Shillings are from United States Bureau of the Census (1970, Series Z 337-356).

Price of a bushel of wheat in PA pounds is Column 2 divided by 20 (20 shillings in a pound).

The Exchange Rates on London PA currency are from Bezanson (1951).

The price of a bushel of wheat in pounds sterling is Column 3 divided by the exchange rate on London PA currency for £ sterling.

The dollar value of a bushel of wheat in Column 6 is Column 5 multiplied by \$5 and the dollar value of a bushel of wheat in column 7 is Column 5 multiplied by \$4.58.

Table 2.10**Dollar Value of a Barrel of Pork**

Year	Price of a Barrel of Pork in Pennsylvania Shillings	Price of a Barrel of Pork in Pennsylvania Pounds	Exchange Rate on London Pennsylvania Currency for £100 Sterling	Price of a Barrel of Pork in £ Sterling	Dollar Value of a Barrel of Pork (£1 Sterling = 4.59 US dollars)
1700-1719	46.46	2.32	133.33	1.74	\$8.00
1720-1724	42.60	2.13	133.33	1.60	\$7.33
1725-1729	49.40	2.47	155.00	1.65	\$7.56
1730-1734	51.20	2.56	160.00	1.60	\$7.34
1735-1739	49.80	2.49	164.50	1.51	\$6.95
1740-1749	56.60	2.83	170.00	1.66	\$7.64

Notes and Sources: The exchange rate from 1700-1719 was assumed to be the same as the exchange rate in 1720. The exchange rates in subsequent time periods are the averages of monthly rates of exchange. See Table 17, page 413 of Bezanson (1951).

Prices of a pound of pork in Pennsylvania Shillings are from United States Bureau of the Census (1970, Series Z 337-356).

Price of a pound of pork in PA pounds is Column 2 divided by 20 (20 shillings in a pound).

The Exchange Rates on London PA currency are from Bezanson (1951).

The price of a pound of pork in pounds sterling is Column 3 divided by the exchange rate on London PA currency for £ sterling.

The dollar value of a pound of pork in Column 6 is Column 5 multiplied by \$5 and the dollar value of a pound of pork in column 7 is Column 5 multiplied by \$4.58.

Table 2.11**Dollar Value of a Bushel of Beef**

Year	Price of a barrel of beef in Pennsylvania Shillings	Price of a barrel of beef in Pennsylvania Pounds	Exchange Rate on London Pennsylvania Currency for £100 Sterling	Price of a barrel of beef in £ Sterling	Dollar Value of a Barrel of Beef (£1 Sterling = 4.59 US dollars)
1700-1719	30.00	1.50	133.33	1.13	\$5.16
1720-1724	30.75	1.54	133.33	1.15	\$5.29
1725-1729	33.50	1.68	155.00	1.12	\$5.13
1730-1734	33.50	1.68	160.00	1.05	\$4.81
1735-1739	34.80	1.74	164.50	1.06	\$4.86
1740-1749	40.10	2.01	170.00	1.18	\$5.41

Notes and Sources: The exchange rate from 1700-1719 was assumed to be the same as the exchange rate in 1720. The exchange rates in subsequent time periods are the averages of monthly rates of exchange. See Table 17, page 413 of Bezanson (1951).

Prices of a barrel of beef in Pennsylvania Shillings are from United States Bureau of the Census (1970, Series Z 337-356).

Price of a barrel of beef in PA pounds is Column 2 divided by 20 (20 shillings in a pound).

The Exchange Rates on London PA currency are from Bezanson (1951).

The price of a barrel of beef in pounds sterling is Column 3 divided by the exchange rate on London PA currency for £ sterling.

The dollar value of a barrel of beef in Column 6 is Column 5 multiplied by \$5 and the dollar value of a barrel of beef in column 7 is Column 5 multiplied by \$4.58.

Table 2.12

Dollar Value of a Bushel of Rye

Year	Price of a bushel of rye in Pennsylvania Shillings	Price of a bushel of rye in Pennsylvania Pounds	Exchange Rate on London Pennsylvania Currency for £100 Sterling	Price of a bushel of rye in £ Sterling	Dollar Value of a Bushel of Rye (£1 Sterling = 4.59 US dollars)
1700-1719	2.05	0.10	88.89	0.08	\$0.35
1720-1724	2.53	0.13	88.89	0.09	\$0.43
1725-1729	2.41	0.12	103.33	0.08	\$0.37
1730-1734	2.06	0.10	106.67	0.06	\$0.29
1735-1739	2.31	0.12	109.67	0.07	\$0.32
1740-1749	2.41	0.12	113.33	0.07	\$0.33

Notes and Sources: The exchange rate from 1700-1719 was assumed to be the same as the exchange rate in 1720. The exchange rates in subsequent time periods are the averages of monthly rates of exchange. See Table 17, page 413 of Bezanson (1951).

Prices of a bushel of rye in Pennsylvania Shillings are from Brooke Hunter (2005). She suggests that wheat typically sold at prices one-half greater than rye. Rye prices were calculated using known wheat prices and the conversion factor suggested by Hunter.

Price of a bushel of rye in PA pounds is Column 2 divided by 20 (20 shillings in a pound).

The Exchange Rates on London PA currency are from Bezanson (1951).

The price of a bushel of rye in pounds sterling is Column 3 divided by the exchange rate on London PA currency for £ sterling.

The dollar value of a bushel of rye in Column 6 is Column 5 multiplied by \$5 and the dollar value of a bushel of rye in column 7 is Column 5 multiplied by \$4.58.

Table 2.13

Prices of Wheat, Pork, Beef, and Rye

Birth Date	Price of a Bushel of Wheat	Price of a Barrel of Pork	Price of a Barrel of Beef	Price of a Bushel of Rye
1700-1720	\$0.53	\$7.84	\$5.06	\$0.35
1720-1724	\$0.65	\$7.19	\$5.19	\$0.44
1725-1729	\$0.55	\$7.41	\$5.03	\$0.37
1730-1734	\$0.44	\$7.20	\$4.71	\$0.30
1735-1739	\$0.48	\$6.81	\$4.76	\$0.32
1740-1749	\$0.49	\$7.49	\$5.31	\$0.32

Notes: Price of wheat, pork, beef, and rye are from Tables 9, 10, 11, and 12.

Table 2.14

Distribution of Estimated Protein Surplus

Birth Date	Average Bushels of Wheat Per Day	Average Barrels of Pork Per Day	Average Barrels of Beef Per Day	Average Bushels of Rye Per Day
1700-1720	0.068	0.003	0.001	0.003
1720-1724	0.076	0.004	0.002	0.032
1725-1729	0.071	0.004	0.002	0.030
1730-1734	0.045	0.002	0.001	0.019
1735-1739	0.062	0.003	0.001	0.026
1740-1749	0.088	0.005	0.002	0.037

Notes: Bushels of wheat and rye and barrels of pork and beef per day per capita generated from Haines et al. regression coefficients with intercept adjustment.

Table 2.15

Estimated Income Per Capita

Year	(a) Estimated Per Capita GDP (Egnal Percentage: 48 percent)	(b) Revised Estimate of Per Capita GDP (58 percent)	(a) Estimated Income Per Capita (In 1990 Dollars)	(b) Estimated Income Per Capita (In 1990 Dollars)
1700-1720	\$49.67	\$41.11	\$1007	\$843
1720-1724	\$74.44	\$61.61	\$1551	\$1,283
1725-1729	\$64.80	\$53.63	\$1181	\$981
1730-1734	\$35.80	\$29.62	\$847	\$701
1735-1739	\$50.47	\$41.77	\$1177	\$974
1740-1749	\$74.63	\$61.77	\$1585	\$1310

Notes: GFP per capita per day are estimated using Equation 2.2.

Column 4 is Column 4 in 1990 dollars.

Column 5 is Column 5 in 1990 dollars.

Columns 4 and 5 were estimated for the eighteenth century using John J. McCusker's (2006) estimates.

Table 2.16

Average Annual Rates of Change

Year	Average Annual Rates of Change
1710-1722	0.04
1722-1727	-0.05
1727-1732	-0.07
1732-1737	0.07
1737-1745	0.04
1710-1745	0.01

Notes: The Year column is the midpoint of each range of years listed in Table 15.

3. Chapter 3: Convergence and the Biological Standard of Living in the United States

3.1 Issues

Among economists the comparison of living standards across geographical regions dates from Adam Smith. Examining the economic performance of Britain relative to her colonies, Smith observed “the rapid progress of our American Colonies towards wealth and greatness.” Furthermore, Smith reasoned a specific set of characteristics explained this “wealth and greatness,” and the absence of such characteristics spelled poverty:

“A particular country ... may frequently not have capital sufficient both to improve and cultivate all its lands, to manufacture and prepare their whole rude produce for immediate use and consumption, to transport the surplus part either of the rude or manufactured produce to those distant markets where it can be exchanged for something for which there is a demand at home.”²³

Karl Marx addressed the connection between standard economic indicators and biological ones through his writings of the negative externalities that accompanied industrialization. Recognizing the role of stature in his assessment of the declining welfare of the population, he used the declining heights of the French and German military recruits as evidence of the need for political reform.

“The limiting of factory labor was dictated by the same necessity which spread guano over the English fields. The same blind eagerness for plunder that in the one case exhausted the soil, had, in the other, torn up by the roots the living force

²³ Smith (1937, p. 346-347).

of the nation. Periodical epidemics speak on this point as clearly as the diminishing military standard in Germany and France.²⁴

With the advent of national income accounting in the twentieth century, economists took a more comprehensive look at the comparative performance of nation states. Since Alexander Gerschenkron's (1962) seminal work on "economic backwardness" and Simon Kuznets' (1966) work on "modern economic growth," economists have focused on explaining growth rates across countries. More recently, Baumol (1986) and Barro and Sala-i-Martin (1991) present formal models of per capita income convergence across countries, and subsequently the topic has been extensively explored and developed in both empirical and theoretical literatures. While previous studies have focused on standard economic indicators, such as wages, gross domestic product, and per capita income, the present study investigates the convergence of biological indicators of the living standard. Specifically we answer the question of whether human stature tended to become more similar across regions in the nineteenth century in the United States, that is, did stature converge to a long-run national norm?

Human stature is among the ultimate biological manifestations of the consumption of net nutrients, and as such, stature serves as a primary indicator of the biological standard of living (Steckel 1995). Stature measurements in early American history can be used to assess how historical events, including the expansion of agricultural output, urbanization, and the improvement of the transportation network, impacted standard of living and health status. Since the literature and significance of studying stature is relatively new in economics, a brief review of the application of stature to the issues associated with changes in living standards would seem to be in order.

Arguably the most common objection to the use of stature as an economic indicator is that height is hereditary. One of the foremost experts on human growth, J.M. Tanner, disputes

²⁴ Marx (1867) as quoted in Floud (1994), p. 15.

most vigorously this sentiment, observing, “Statements such as ‘Height is an inherited characteristic’...are intellectual rubbish, to be consigned to the trashcan of propaganda” (Tanner 1978, p.117). He argues the only thing inherited is DNA and everything else is developed. Adult height is then the result of both genes and the environment. The prominent geneticist, J.M. Thoday, supports Tanner’s position: “No characteristic is largely acquired. Every characteristic...is entirely acquired” (Thoday, 1965, p. 94). While a person’s genes may determine adult height potential, whether the potential is realized or not depends on the environment. To be clear the role of genetics is not being denied, but in the realization of biological outcomes as opposed to biological potential, the role of environmental variables is just as essential.

It is crucial to emphasize that heights of individuals are not being studied in the standard of living literature. What is important is how the mean height of homogeneous groups of individuals has changed over time. The comparison over time will then reflect environmental changes, including nutrition, work intensity, and exposure to disease. Therefore, comparing mean heights of groups captures growth patterns determined more by environmental factors than by genetics; while a comparison of individual heights would reflect strong genetic influences. So, for example, when net nutritional status diminishes for some members of a population, the environmental influences will dominate genetic influences and will result in variation of achieved adult stature even within populations of the same genetic make-up.

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 cause growth to cease. 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 food prices, work conditions, and disease environment can all influence net nutritional status. Therefore the change in adult mean stature within a country over time

documents, to a substantial extent, change in the economic and social climate. Stature is a unique variable in that it offers a measure of the “actual physical outcomes of economic activity” (Cuff 2005, p. 11).²⁵

Thus height is a function of net nutrition, which in turn is a function of environmental factors. Eveleth and Tanner (1976, p. 222) explain how overall height is determined by genetic and environmental factors during the time of growth.

“Such interaction may be complex. Two genotypes which produce the same adult height under optimal environmental circumstances may produce different heights under circumstances of privation. Thus two children who would be the same height in a well-off community may not only be smaller under poor economic conditions, but one may be significantly smaller than the other.... If a particular environmental stimulus is lacking at a time when it is essential for the child (times known as ‘sensitive periods’) then the child's development may be shunted as it were, from one line to another.”

Human growth is characterized by two main times of heightened growth activity. The first occurs in infancy and the second occurs in adolescence. Because of the inherent course of the physiological development of homo sapiens, environmental factors play an especially important role in the growth of small children and adolescents. The velocity of growth during infancy is approximately twice what it is in adolescence. Environmental insults can alter both the tempo and velocity of growth and make it more difficult for the person to reach their genetic height potential.

Nutrition directly impacts both the tempo and velocity of growth. The body first uses nutrition for maintenance. Additionally disease and work intensity can increase caloric demands. Tanner (1978) notes that for a one year old child the amount of energy needed for bodily

²⁵ See Cuff (2005) for a summary of these issues.

maintenance is more than ten times what is necessary for normal growth and four times what is used for physical activity. What is left over – i.e. net nutrition – fuels human growth. Nutritional status heavily influences the extent to which disease pathogens impact the body and the relationship between disease encounters and nutritional status has been described as synergistic.²⁶ Malnutrition or excessive physical activity makes the body more susceptible to disease or sickness, further decreasing the amount of nutrition available for growth.

If there is a nutritional deficiency in either the infancy or adolescent period of growth, then there is a limited window of time the nutritional deficiency can be reversed so adult stature is ultimately not adversely affected. When there are poor environmental circumstances the body will begin to slow the tempo of growth in order to supply nutrients for other purposes, such as combating disease or malnutrition.²⁷ When the excess demands on the body are removed, nutrients will once again be relegated to growth and catch-up growth will occur, delaying the age a person achieves their full stature. The length of time the excess demands are placed on the body determines the degree of catch-up growth. If the period is too long, catch-up growth will still take place, but genetic height potential will not be fulfilled. Tanner (1994) notes that developing economies are sensitive to negative changes in disease environment or nutrition and this can impede catch-up growth, as the extra calories needed later might not be available.

Changes in the environment will be the driving force behind changes in average height since genetic differences – i.e. divergence from the mean - approximately cancel in averages across populations. Malcolm's (1974) study, which involves Europe, New Guinea, and Mexico, suggests environmental factors are of great significance when analyzing height at any stage of growth and differences in mean stature between groups of children could be attributed more to

²⁶ Cuff for instance. And Steckel, and Tanner.

²⁷ Malnutrition can change the tempo of growth and this should not be taken as evidence adult height will be stunted.

environmental factors than genetic ones.²⁸ For example, at first glance the case of Far-Eastern populations would seem to imply genetics plays a dominant role in the relatively small stature of the groups. But in the period 1957-1977, estimated height measurements increased for young adults in both decades (Tanner et al. 1982)²⁹, possibly indicating the difference between this group and Western populations is not driven as much by genetics as once believed.

Eveleth and Tanner (1976) suggest Europeans, people of European descent, and Africans and people of African descent achieved similar adult stature when faced with favorable environmental conditions. The finding is salient to the present study because the heights data employed below reflect the fact that the majority of the migrants to the United States in the nineteenth century were from these areas. The fact that the populations from these regions reached similar heights dampens the degree of genetic influence that might otherwise weaken the results of the study. In other words, because the data represent individuals drawn from a single genetic pool – specifically, native-born white males of European descent – genetic factors, both individual and across populations play no role in determining the differences in stature over space or time, which we observe and examine.

The consumption of nutrients – net of those exhausted during work or while fighting disease – determines whether *homo-sapien* populations achieve their genetic height potential. Since food consumption in the early phase of the Industrial Revolution accounted for three fourths 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, 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). However, increases in income during the early phases of industrialization may not have had the same

²⁸ For instance, differences in the rate of growth among school age children were primarily attributed to variation in protein intake.

²⁹ Leg-length accounted for almost all of the secular height change.

positive impact as they did subsequently. Indeed it appears higher incomes were spent, at least partly, on alcohol, tobacco, sugar, and in general less healthy diets (Clark et al. 1995).

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.

A low level of income limited the quality and quantity of food intake, and rising incomes were often associated with jobs requiring hard labor, long hours, and working conditions that were unpleasant and dangerous for long periods of time. This placed increased demands on nutrition entering the body for maintenance, leaving little left over for growth. The affordable foods were more likely to be high in carbohydrates (e.g. grains, which were less perishable than meat and dairy products) and less likely to provide the additional nutrients needed for catch-up growth when a nutritional deficiency occurred in a critical period of development—particularly infancy and early adolescence.³⁰ Table 1 demonstrates a British estimate of the decline in real prices of sugar and bread relative to the increasing real prices of meat, bread, butter, and cheese.

Cultural impacts on personal and household hygiene; as well as technologies, such as running water, sewers, and washing machines; the impact of work intensity, and the relative price of key foods, such as fresh meat and dairy products, cannot be ignored either (Mokyr 2000). The emergence of factories increased urbanization and concentration of the workforce, leading to increased exposure to infectious disease. The absence of public health measures can create an environment ripe for disease. While the discussion of the economic impact on stature is tailored

³⁰ This should not be taken as evidence that low-income individuals went hungry. As Komlos (1998) suggests, “Utility is maximized subject to a weight (or volume) constraint not a nutrient constraint, inasmuch as consumers did not know about nutrient contents of food such as vitamins, minerals, and proteins.”

for a developing country, the argument can be extended to the history of industrialized countries.³¹

Paradoxically, in the mid-nineteenth century United States, stature declined, but economic growth, as measured by the growth of income per capita, increased (See Table 4, below). The phenomenon is referred to as the “Antebellum Puzzle” (Komlos 1996; Haines et al. 2003; Craig et al. 2004). The divergence of the two standard of living measures highlights the importance of studying stature. The divergence between economic and biological indicators suggests one cannot focus solely on income as a way to describe the overall economic climate of the times. This is especially true when the environment is teeming with change as a result of complex interactions of life and work patterns. Many of the nineteenth century patterns produced negative health and mortality consequences. Drawing conclusions from income observations would be misleading if the change in environment were not taken into account. If the decline in net nutritional status overshadows the advantages conferred by higher incomes, then the mere fact that incomes have risen cannot be interpreted as a sign that on average people were unambiguously better off (Floud 1994).

In attempting to identify the cause of the puzzle, economic historians have identified a number of suspects. The absence of the germ theory of disease would have limited the benefits high-income populations derived from increased access to healthcare. Urbanization also could account for the decline in height as populations were living closer together and the possibility of disease spreading was higher in the absence of effective public health measures.³² The increase in population forced farmers to search for new land less suitable for farming - decreasing marginal products, *ceteris paribus*, of course - and increasing the risk of disease, most notably malaria. The rising price of food, especially animal products, would have caused some people to

³¹ Eveleth and Tanner, 1976.

³² Steckel (1995) finds a statistically significant inverse relationship between height and the percent of the population that was urban in the mid nineteenth century.

substitute carbohydrate rich foods (sugar, grains) for protein rich foods (meat and dairy products), thereby robbing growth of a fundamental input (Komlos 1994; Komlos and Coclanis 1999).

While transportation improvements allowed larger segments of the population to enjoy a more varied diet, they came with a cost, as food was less dense in nutrients on arrival.³³ In general, these factors reflect rising inequality associated with industrialization (Steckel and Moehling 2001). In addition, increased migration and trade expanded the disease nexus.

Figure 3.1 illustrates average adult height for native-born white males, by birth cohort, for each decade between 1800 and 1900. The graph shows there is not a unidirectional, upward trend in stature in the nineteenth century and the United States has exhibited cycles in height. Human stature rose early in the century, fell mid-century, and began to rise again at the end of the century. Americans born before 1840 were taller than Americans born in subsequent decades. Specifically, those born in 1830 were more than an inch taller than those born in 1890. Although mean height bottomed out with the birth cohort of 1890, and began rising thereafter, mean height did not reach 1830 levels again until 1920.

Despite the decline after 1830, by global standards Americans were tall in the early decades of the century. American colonists tended to be taller than Europeans because they were experiencing slower industrialization, had greater food resources, lower levels of income inequality, and their population was small and dispersed enough so disease could not be spread at as rapid a rate as in the more urbanized and developed European countries.³⁴

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. Figure 3.2 shows the height and GDP trends in the nineteenth century for the United States. The figure shows the divergence of height and

³³ Refrigeration played a role in food preservation after 1890 (Craig et al. 2004).

³⁴ For a detailed account of stature in the American colonies and early republic, see Treme (2005).

income measures. 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.

The stature literature examines the relationship between income and height—using height as an indicator of health—and the socioeconomic and geographical determinants of height; however the extension of the convergence idea to stature has not been pursued in previous research. Convergence examines the effect of initial conditions on long-run economic outcomes. If the effect of the initial condition eventually dies out – with initially shorter regions having higher growth rates than taller ones – then the absolute convergence hypothesis holds and the short converge on the tall from below. If one fails to find evidence of absolute convergence, it is possible to test for the existence of conditional convergence, which reflects the possibility that while initial conditions die out, each region moves to its own (long-run) steady state rather than a universal steady state. If conditional convergence were present, poor (short) regions would grow faster than rich (tall) ones but only after controlling for other variables that influence the steady state differences.

As each adult faces a biological height bound, so does each society. There are in fact height limits no amount of nutrition or medical care can help to surpass. With every improvement in nutrition, medical care, and technology, a society will take one step closer to achieving an average height equal to its biological bound. Evidence of groups of economies moving towards their biological height bounds will suggest improvements in human welfare. One way to assess whether a society is moving towards its biological height bound is to test for the presence of convergence, or whether initially shorter populations have higher growth rates

than those experienced by taller populations.³⁵ Thus in what follows we test for these various forms of convergence, and we answer the question of whether and how heights converged (or diverged) across the various regions in the United States during the nineteenth century.³⁶

3.2 Model

The basic framework for testing for convergence was laid out by Barro (1991) and Barro and Sala-i-Martin (1992), and addresses the question of whether poor regions or countries tend to grow faster than rich ones. The papers analyze the forces leading to convergence over time in the levels of per capita income and product. Specifically, Barro uses the U.S. states and Barro and Sala-i-Martin use countries to study convergence. They find evidence of convergence: poorer regions and countries do grow faster than rich ones on average. Barro uses a neoclassical growth model for closed economies, as presented by Ramsey (1928), Solow (1956), Koopmans (1960 and 1965) and Cass (1965). One of the results of Barro’s work on the subject was the birth of the so-called “Barro regression,” which is used in the empirical section below.

Specifically, Barro estimates the following nonlinear univariate equation

$$\frac{1}{T} \log\left[\frac{y_{i,T}}{y_{i0}}\right] = a - \left[\frac{1 - e^{-\lambda T}}{T}\right] * \log(y_{i0}) + w_{i0,t} \quad (3.1)$$

where y is income; T is time; λ is the speed of convergence, and w is a disturbance term. If $\lambda > 0$, then Equation 3.1 implies that poor economies tend to grow faster than rich ones. Another

³⁵ As improvements in environment, medical care, and nutrition become available to broader segments of society, the growth rate of stature would be lower for the taller populations, as they are closer to their biological bound than the shorter populations.

³⁶ For a criticism of this so-called “beta” convergence, see Quah (1993) and Bernard and Durlauf (1996).

way of saying this is that if the estimated coefficient in front of the log of initial income is negative, then one can conclude that absolute convergence occurs – or more specifically, one cannot reject the null hypothesis of no convergence.

Thus the following more general version of Barro’s equation can be used to test the absolute convergence hypothesis as it relates to height:

$$h_{i,t,t+T} = a + \beta \log h_{i,t} + e_{i,t} \quad (3.2)$$

where the dependent variable, $h_{i,t,t+T}$, is the growth rate of height between t and t+T and is

measured as $\frac{\log h_{i,t+T} - \log h_{i,t}}{T}$ and the independent variable, $\log h_{i,t}$, is the natural log of

height at time t. If the sign on β is negative, and if one can reject the hypothesis that $\beta=0$, then it can be said that the data exhibit absolute beta convergence. In short, one is rejecting the null hypothesis of no convergence, and by extension one can conclude that stature of the population of each region is converging to a common height.

It follows then that the present study is most notably interested in the sign of β . To obtain β , it is only necessary to run an ordinary least squares regression and observe whether the covariation between the growth rate of height over time and the log of initial height is negative. Absolute convergence implies a negative sign and indicates all states will eventually grow at the same rate and the differences in height were only temporary. States with populations further from the common steady state of height must grow at a faster rate in order to achieve absolute convergence.

If β is positive, then there is evidence of divergence. In terms of height, divergence would imply an increasing gap in the difference between average heights across states. If average

height were increasing over the relevant time period, the relatively tall states would experience larger increases in average height when divergence was present. On the other hand, if average height were declining over time, divergence would indicate that the relatively short states were experiencing more rapid declines in average height. Divergence is an indication that there is significant heterogeneity among states that makes convergence impossible for these regions.

While Barro's paper focuses on the log level of per capita output at time t , the choice of variable can extend to such uses as fertility rates, life expectancy, real wages, and as noted above, height. Of course, some variables trend downward in the long run, such as fertility rates. The so-called demographic transition, during which crude birth rates fell on average from around 50 per thousand population to less than 20 per thousand, represents such a case. Here, countries displayed a form of negative convergence. That is to say, the high fertility countries converged on the low fertility countries from above; thus the new steady state was at a lower fertility level. Therefore, in order for average height to converge, short states must grow faster than tall states to converge to a higher steady state or tall states must experience larger, negative growth rates than short states to converge to a lower steady state.

3.3 Results

To investigate the questions outlined above, we employ a unique data set, which contains estimates of mean adult height, by birth cohort, for native-born white males in ten-year intervals from 1800 to 1900. The base data are from Craig and Weiss (1998) and Haines, Craig, and Weiss (2003) and consist of a sample of Union Army recruits from data originally collected by Fogel, Engerman et al. (ICPSR). It includes recruits born in the nineteenth century for whom information was available on, among other things, place of birth and adult height. Obviously,

there were some states in some years for which there were no observations. Following Craig and Weiss (1998), the missing observations were estimated based on the underlying economic relationship between adult stature, net nutrition, and economic environment.³⁷

In order to check the accuracy of our estimates using the technique described above, we used our state-level estimates to construct national estimates, which we then compared to other national estimates and benchmarks. Table 3.2 illustrates the results of this comparison. With the exception of 1900, the estimates are very close to other benchmark figures found in Steckel (1995) and Costa and Steckel (1997). Indeed, in eight of the eleven years, the differences in the means were smaller than eight-hundredths of an inch. Thus we are confident the technique produces estimates that do not deviate too greatly from the true data.

Table 3.3 contains the least squares estimates, in the form of a Barro regression, for 26 U.S. states for various, overlapping time periods in the nineteenth century. Since decadal data is only available for 26 states from 1820-1900, the sample is limited to restrict attention to the changes in average height over the same set of states. The Barro equation used to test for absolute convergence is

$$\text{Growth Rate of Height} = \alpha + \beta \text{ Log of Initial Height} + e_{i,t} \quad (3.3)$$

The dependent variable is the growth rate in height over a twenty-year period beginning in year t , and the independent variable is the log of initial average height in year t . For example, in column 1 the variable Log of Initial Height is the log of average height for 1820, and Growth Rate of Height is the growth rate between 1820 and 1840. Each cell represents the estimate of β , the

³⁷ See Chanda, Craig, and Treme (2006).

standard error for this estimate (in parentheses), and the R^2 . All equations have been estimated with constant terms that are not reported in the table.

Absolute divergence is evident in the first four regressions. The coefficient on the β 's is positive and significant indicating that on average, there is an increasing gap in the difference between average heights across states. The relationship between the growth rate and initial average height is shown in Figures 3.3-3.6.

Figures 3.3-3.5, covering the period 1820-1860, show the growth rate of mean adult stature was negative and thus average height declining across the United States. This is the “antebellum puzzle.” While no state experienced an increase in height over the initial three time periods, there is evidence of absolute divergence, or a widening gap between the tall and short states. As an example, compare the position of Rhode Island and Arkansas as they appear in Figures 3.3-3.5. Rhode Island is consistently one of the shortest states and experiences larger growth rate declines than nearly every other state in the sample. Arkansas is consistently one of the tallest states and the growth rate declines are smaller than nearly all other states in the sample. The gap is widening because an initially short state, Rhode Island, is shrinking faster than an initially tall state, Arkansas.

Contrast antebellum height behavior with income measures over the same time period. Table 3.4 shows antebellum income estimates. From 1800-1860, real GDP capita grew at 0.92 percent per annum. The pace was even higher for the decades 1830-1860 as the average annual growth rate of real GDP per capita was 1.33 percent. The income evidence in Table 3.3 and the average height measurements in Figure 3.1 illustrate the divergence of income and height trends that define the “Antebellum Puzzle”.

Figure 3.6 also displays absolute divergence, but the growth rate was positive for 15 of the 26 states. The increasing height of subsequent birth cohorts in the tall states and simultaneous

decline in the short states caused the height gap to widen. The tall were getting taller, or still in some cases shorter at a slower rate, while the short were getting shorter. For instance, Arkansas was getting taller while Rhode Island was still shrinking. This represents divergence, though a slightly different type of divergence than in the earlier decades in which the mean heights were falling across the board.

As the divergence dies out in this developing economy, a post-Civil-War problem emerges. Initially “tall” states begin to experience larger height declines than initially “short” states. The β coefficient for the regression 1870-1890 is negative and significant. The relationship can be appreciated from the scatter plot in Figure 3.7 of the average growth rate of height between 1870 and 1890 against the log of height in 1870. The negative coefficient is statistically significant at the 1 percent level suggesting absolute convergence across states, but it is convergence of a peculiar kind—peculiar at least by the standards of Barro’s results and what is generally seen in the growth literature. Since the growth rates were negative, as evidenced by the graph, states with a higher average height in 1870 experienced larger declines in their growth rates than states with a lower average height. Regional stature is converging to a common height, but one that is shorter in 1890 than earlier. In other words, states are displaying a form of negative convergence in that the tall states converged on the short states from above; thus the new steady state was at a lower height level. Thus the puzzle continues.

The simple relation between growth rates and initial levels of height is not significant in either the 1860-1880 period or the 1880-1900 periods. The coefficient on β is insignificant and positive over the period 1860-1880 and insignificant and negative over the period 1880-1900. The divergence and negative convergence associated with the antebellum puzzle appears to be at an end, but the result suggests it may be necessary to test for conditional convergence, especially because of the spike in heights in 1870 (see Figure 3.1).

The Barro equation used for conditional convergence is

$$\text{Growth Rate of Height} = \alpha + \beta \text{ Log of Initial Height} + \psi V + e_{i,t} \quad (3.4)$$

Where V is a vector of additional explanatory variables; thus this regression holds the additional explanatory variable constant to obtain an accurate estimate of β . Conditional convergence abandons the assumption that all states have homogeneous environments and steady state positions, and it implies states will grow faster the further they are from their own steady-state value. The new explanatory variables influence the growth rate and are therefore determinants of the steady-state position. After controlling for factors impacting steady state positions, conditional convergence implies a negative partial correlation between growth and initial level of height. For instance, holding the new explanatory variable constant, states with low average heights must grow at a faster rate than states with high average heights in order to achieve conditional convergence.

A possible explanatory variable affecting steady state positions is geographic location. Urbanization would have played a role in the decline in heights as populations were living closer together and the possibility of spreading disease was higher. States in the South were more likely to be rural than Northeastern states. Therefore, on average, Southern males would be expected to be taller than males of the Northeast. Thus a regional dummy for the South has been added as an explanatory variable to capture effects common to states in this region.³⁸

Table 3.5 shows least squares estimates in the form of a Barro regression testing for absolute and conditional convergence. As with table 3.3, each column contains an estimate of β , the standard error for this estimate (in parentheses), and the R^2 . Conditional convergence

³⁸ The dummy variable takes on the value one for the following southern states: Virginia, Arkansas, South Carolina, Georgia, Tennessee, Alabama, Mississippi, Arkansas, and Louisiana; zero otherwise.

regressions additionally estimate a southern regional dummy whose estimate of β and its standard error are also reported in the table.³⁹

When the dummy variable for the South was added to the regression over the time period 1860-1880, the estimated β coefficient was positive and insignificant. Figure 3.1 above shows that the United States experienced cycles in average height in the nineteenth century, with average heights rebounding briefly in 1870. Given the rebound of height in 1870 and the subsequent decline and then rebound again after 1880, the 1870s appears to be an anomalous decade. Perhaps the uneven recovery from the war, rapid in some places and slow in others - contributed to this record. In any case, it might be worth confining the convergence tests to ten-year periods.

Figure 3.8 shows the relationship between the growth rate and initial log of height. Figures 3.9 and 3.10 show the relationship between the filtered growth rate and initial log of height when the regional dummy variable is held constant. The log of average height of each state in 1860, 1870, and 1880 is shown on the horizontal axis. The vertical axis displays the growth rate of average height from 1860-1870, 1870-1880, and 1880-1900 respectively. The growth rates in Figures 3.9 and 3.10 differ from Figures 3.3-3.8 because they are filtered for the estimated effect of the Southern region explanatory variable. Note that once the region is controlled for, the gap between tall and short states begins to shrink because taller states experience higher, negative growth rates than shorter states.

Significant absolute divergence was found in the 1860-1870 period. Figure 3.8 is similar to Figure 3.6 and demonstrates the positive relationship between growth rates and initial height over the period 1860-1870. A tall state, like Arkansas, in 1860 would grow faster than a short state, like Rhode Island, and thus increase the height gap. This is divergence.

³⁹ All equations have been estimated with constant terms that are not reported in the table.

As shown in Figure 3.9, the result turned around after 1870, suggesting the return of the antebellum puzzle- now a postbellum puzzle. The similarity can be seen when compared with Figure 3.7. When the dummy variable for the South was added to the regression over the time period 1870-1880, the estimated β coefficient was significantly negative and confirmed the existence of conditional convergence. The states with short populations begin to see their mean height decrease more slowly than states with tall populations. In short, the tall are converging on the short from above. Of course this holds conditionally, that is to say only if the Southern region dummy variable is included.

Overall, the offsetting effects of negative conditional convergence in the 1870-1880 period and absolute divergence in the 1860-1870 period must be driving the insignificant convergence over the 1860-1880 period. That is, once the southern region is controlled for, and the twenty-year period broken in two sub-periods, the decline in the growth rates of height in the 1870-1880 decade are balanced by the average height gains in the 1860-1870 decade.

While absolute convergence was not found in the 1880-1900 period, conditional convergence is evident for the 1880-1900 period. The estimated regression including the southern region dummy yielded a significant and negative β coefficient. The coefficient implies a negative, partial relation between filtered growth rates and initial income. Figure 3.10 displays the relationship. After region is controlled for, growth rates were mainly positive, implying a form of positive convergence. This is a Barro-type of result in that shorter states were growing faster than taller states to close the height gap, and marks the end of the antebellum puzzle. Mean adult stature begins to display classic convergence behavior and follows the standard economic indicators after 1880.

3.4 Discussion

The pattern of convergence demonstrated in Figures 3.3-3.10 shows the evolution of an economy as it experiences divergence, negative convergence and ultimately positive convergence. The widening height gap between the tall and short populations in the early part of the century can be attributed to urban and rural differences, transportation improvements, and industrialization; while the negative convergence found toward the end of the century can be explained by increasing commercialization efforts, particularly in the South. An unexpected Midwest height decline in the period 1870-1890 can be accounted for by an increasing income inequality, coal interest, and urbanization. The positive convergence at the end of the century indicates the economy is moving towards an advanced stage of development through a type of socio-biological arbitrage.

3.4.1 Antebellum Period and Divergence

The divergence evident in Figures 3.3-3.5 is consistent with previous research of the antebellum period. The divergence can be attributed in part to differences between urban and rural areas. Urbanization would have contributed to the decline in heights 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 stature decline for birth cohorts from 1830 to 1860. Steckel (1995) notes a rural height advantage throughout the nineteenth century with its peak occurring in the early part of the century. Haines et al. (2003) provides further evidence of a negative relationship between height and urbanization during the antebellum period.

The urban-rural height differential can be decomposed further by considering geographic location. States in the South were more likely to be rural; whereas Northeastern states were more likely to be urban. Therefore, on average, Southern males would be expected to be taller than males of the Northeast, *ceteris paribus*, of course. The present study bears this out, as Northeastern populations were shorter than their Southern counterparts in every decade. Referring back to Figures 3.3-3.5, a tall, Southern state, such as Arkansas, incurred smaller growth rate declines than a short, Northeastern state, such as Rhode Island.

Clark et al. (1995) suggests the divergence may also be attributed to diet differences between urban and rural areas. In addition, Steckel and Moehling (2001) report more inequality among urban population relative to rural ones. As incomes rose, people were able to purchase a greater variety of food products. The choices they made impacted their growth and subsequently their stature. Stature is determined by cumulative net nutritional status that depends on both nutritional inputs and demands. Rural areas consumed nutrient-rich foods that were high in protein, such as grains, milk and cheese. In contrast, urban diets were high in caloric quantity - including sugar and alcohol - but less likely to be the type of nutrients necessary to fuel growth. This was a consequence of the nutrient source shifting away from fresh meat and dairy produced and consumed on the farm and towards processed foods and beverages in urban areas. The lack of quality nutrients and protein would have diminished net nutritional status and slowed or even stunted growth in urban areas. Therefore diet choice would have been a motivating factor behind higher growth rate declines in urban areas.

Transportation played a role in the height differential as well. Komlos (1994) and Craig and Weiss (1998) suggest transportation improvements came with a cost. While the improvements allowed larger segments of the population to enjoy a more varied diet, food was less dense in nutrients on arrival. Northeastern states would have been at a nutrient disadvantage in spite of their expanded access to food. The development of transportation alternatives would have also

spread disease to locations previously isolated from such sickness. The first epidemic appearance of cholera in the United States in the 1830s was spread through trade routes (Steckel 1994).

3.4.2 Negative Convergence Post Antebellum Period (1870-1890)

The period of negative convergence coincides with an increase in the commercialization of the South. Southern attention was diverted from food crops to cotton and iron production. Northern manufacturers began investing in southern mills in the 1880's to avoid dealing with higher-cost northern labor, and organized labor, and the number of cotton mills subsequently exploded. In 1880 there were 160 cotton mills in the south and by 1890, the region boasted over 400 cotton mills.⁴⁰ The national interest in iron and coal spurred investment in the South and growth entered an explosive period in the 1880's that would extend to the early 1900's.

The shift away from food crops had consequences. Komlos and Coclanis (1997) link the antebellum decline in stature to a rise in commercialization, most notably in areas switching to cotton from food crops and dairy cattle. They claim more urban and commercialized areas compromised nutritional status. Since refrigeration did not play a role in food preservation until after 1890 (Goodwin et al. 2002; Craig et al. 2004), a Southern shift to non-food crops meant a rise in the cost of obtaining dairy and meat products. Since the cost of these items is directly proportional to the distance from the closest production point, the increase in income would have been offset by the rise in prices of food for which they formally paid farm-gate prices. If the point of production for dairy products was too far away then consumers could not buy the products at all. Southerners would have responded by substituting less expensive foods in their diet, most notably those rich in carbohydrates. A carbohydrate rich diet is less likely to provide the nutrients and protein needed to facilitate growth. If the diet was eaten for long periods of

⁴⁰ http://us.history.wisc.edu/hist102/weblect/lec02/02_02.htm.

time, catch up growth would not occur and as a result growth would be stunted. While the Komlos and Coclanis argument is directed toward the antebellum period, the continued rise in cotton production, cotton mills, and escalating growth of the iron industry in the South suggest it can be extended to the 1870-1890 period as well.

The relatively small growth rate decline in the South in the antebellum period is more than likely attributable to the South's agrarian economy. Commercialization was beginning to take hold, but Southerners were still able to purchase food at lower costs than other regions (Komlos and Coclanis 1997). As the century progressed, the Southern emphasis continued to shift to cotton and commercial interests and less people were attracted to growing food crops. As agrarian interests waned, the point of food and beverage production began to move further from urban cores and costs to obtain these goods increased. The 1870-1890 period was one showing the decline of southern self-sufficiency manifesting itself through reductions in the growth rate of stature.

Figure 3.7 is noteworthy in highlighting a puzzling midwestern height decline in the 1870-1890 period. The figure indicates the populations of several midwestern states had higher growth rate declines than those in the initially taller southern states. Negative convergence implies a taller state, such as North Carolina, would experience higher growth rate declines than a shorter midwestern state, such as Indiana. Figure 3.7 indicates the populations of several midwestern states had higher growth rate declines than those in the initially taller southern states. Figure 3.11 provides further evidence of the midwestern height decline and shows the trend in height over the nineteenth century for the southern, midwestern, and northeastern regions. On average, the midwestern states experienced the largest height declines in the 1870-1890 period. The surprising decline can be explained by rising income inequality, coal production, and increasing urbanization.

Rising income inequality is known to exert a negative influence on height (Steckel 1983). If income is concentrated, by definition the income increases to the wealthy will have little or no effect on their stature, as they are already achieving their genetically determined maximum. As Steckel (1995) notes, once growth is complete, a rise in income will not lead to additional stature improvements. Rising income inequality can more than offset the effect of the rise in income on height when the number of explanatory variables is expanded to include such factors as disease or diet (Fogel 1986). For instance, if only the wealthy are recipients of the income increases, the negative height effects of disease and diet will dominate the income effect on height, putting downward pressure on average height.

Gregson (1996) suggests location-specific human capital contributed to increasing wealth and income inequality in the Midwest, specifically Missouri. Early arrivers knew the strengths and weaknesses of growing specific crops and the best way to farm their existing crops. An early arriver need not imply a resident of 20 years. Gregson found that arriving only two years before another arriver generated higher mean wealth for the early arriver. The knowledge was valuable as they were able to select the best and most fertile land and rapidly accumulate wealth. Every migrant thereafter purchased inferior land at higher prices, thus detracting from their rents.

In earlier work, Gregson (1993 a and b) showed Missouri had heterogeneous soil types and terrain. Human capital would have generated the highest rents in areas with the most heterogeneous land. The more diverse the land, the more diverse the crop mix, and the larger the rent extracted from the land. Therefore their location specific human capital maximized the rents they earned from the land and concentrated wealth to this select group, contributing to the rising wealth and income inequality in this region.

As the demand for small grains increased the price of wheat and oats, midwestern farmers were given an incentive to farm small grains. Early arrivers would have known small grains can only be grown with certain types of soil using specific farming techniques and would

have used this informational advantage more effectively than later arrivals (Gregson 1996). This was especially true for Missouri and its neighboring midwestern states. The human capital advantage for early arrivers is again evident, especially from 1860 to 1870, and further contributed to the increased wealth and income inequality in the Midwest. While wealth inequality in rural Missouri was lower than it was for the nation in 1870, the human capital advantage combined with increased demand for carbohydrate rich foods make it feasible that wealth accumulation continued to work in favor of the early arrivers as the nineteenth century came to a close. Gregson's human capital theory could explain part of the Midwest pattern in Figure 6, as the wealth gap between early and late arrivers would have continued to widen and contribute to the stature declines in the Midwest.

The decline in midwestern heights is perplexing, since the human capital theory is not an exact match geographically, as Michigan and Ohio remain notable outliers. It is conceivable that industrialization, as represented by, say, the rise of the coal industry contributed to the pattern. The coal industry witnessed remarkable growth in the last quarter of the nineteenth century. As railroads expanded trade opportunities, investors sought to increase the number of coalfields to take advantage of the boom (and consumed coal themselves). From 1870-1890 coal production increased over 300 percent.⁴¹ Industrialization had taken hold of the country and coal was now perceived to be 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.

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

⁴¹ Source: *Fourteenth Census of the United States*, Vol. XI, *Mines and Quarries*, 1922, Tables 8 and 9, pp. 258 and 260 as seen in <http://www.eh.net/encyclopedia/article/adams.industry.coal.us>.

polluting element from coal smoke. There is little evidence of smoke at contemporary coal plants. Contrast this to Atlantic Monthly columnist James Parton's description of coal-producing Pittsburgh in 1868 as "hell with the lid taken off (Gugliotta 2000)." The coal smoke produces sulfur oxide and carbon dioxide, both of which are considered environmentally offensive.⁴²

The upper and middle classes were able to choose to live as far away from the place of coal production as possible. The poor segments of society bore the brunt of the environmental pollution. In Pennsylvania, the leading coal producing state in 1889, working-class men suffered from consistent smoke inhalation and had the highest death rates from acute respiratory disease (Gugliotta 2000). The negative health externalities generated by increased coal production would have hindered the growth process and contributed to the decline in mean height over the time period 1870-1890. 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.

Table 3.6 shows the leading coal producing states in 1889. Five of the states are in the present sample and include Pennsylvania, Illinois, Ohio, Alabama, and Indiana. Note three out of the five are midwestern states.

Coal production is expected to have a negative effect on the growth rate height in the 1870-1890 time period. A cursory look at the means gives support to the theory, as heights in coal producing states declined twice as rapidly as non-coal producing states. Adding the variable to the conditional convergence regression as an explanatory dummy variable can more formally test the theory. Specifically the variable is constructed as the growth rate of coal production per

⁴² This is especially true for carbon dioxide as it is one of the five major greenhouse gases contributing to the greenhouse effect.

capita over the time period 1870-1890.⁴³ The results are shown in Table 3.7 and indicate the coefficient on the coal production dummy variable is negative and statistically significant at the 5 percent level and aids in explaining much of the variation in the growth rate. The result offers insight to the unexpected magnitude of the midwestern height decline as two of the notable outliers, Illinois and Ohio, were leading coal-producing states in 1889.

The 1870-1890 period was also one of increasing urbanization for the Midwest. While the northeastern and southern region's share of the top 100 largest cities in this time either fell or stayed the same, the Midwest's share rose slightly. For instance, in 1870, Chicago's urban population was 298,977 and ranked fifth among the 100 largest U.S. urban places. By 1890 Chicago's urban population more than tripled to 1,099,850 placing them second only behind New York City. Table 3.8 shows the percentage increase in urban population among the midwestern cities⁴⁴ ranked in the top 100 largest urban cities and their 1890 ranking.⁴⁵ Notice the share of the urban population more than doubled for nearly every midwestern city. The negative relationship between height and urbanization would help explain the large declines in the growth rates of height, as the area was urbanizing at a rapid pace.

Overall, the average height decline demonstrated by the negative convergence results in Figure 3.7 in the 1870-1890 time period can be explained by increased commercialization in the South, increased income inequality in the Midwest, the rise of the coal industry as evidenced by the leading coal-producing states in 1889, and the rapid urbanization of the region.

⁴³ 1.0 was added to all observations to the coal production per capita variable to avoid the problem of taking the logarithm of zero for some observations.

⁴⁴ There are six Midwestern states in the present sample: OH, IL, IN, MO, MI, and KY.

⁴⁵ Percentages computed from 1870 and 1890 U.S. censuses.

3.4.3 Convergence at the end of century

In terms of convergence, height and income patterns begin to coincide at the end of the nineteenth century. The positive conditional convergence found in Figure 3.10 implies a negative, partial correlation between growth and initial level of height. For instance, after controlling for geographic location, initially shorter states grew faster than initially taller states. The onset of the germ theory and improved living conditions played a major role in improving average height as the body had less demands placed on it by disease and poor environmental surroundings and more nutrients were available for growth. Furthermore, although Steckel and Moehling (2001) show a general increase in inequality among the native-born in late nineteenth and early twentieth centuries, the path levels off after 1900, which would have been when the 1880 birth cohort began to reach adulthood.

Barro and Sala-i-Martin (1991) found the same type of convergence when examining income in the late nineteenth century and throughout most of the twentieth century. States with initially lower levels of income had higher per capita growth rates than their wealthier counterparts. The convergence between economic and biological indicators suggests income can be used to accurately describe the overall economic climate as the economy enters a more advanced stage of development.

3.5 Conclusion

Height encompasses a unique information set reflecting the effects of economic activity on the human body. It is most beneficial when studied in the context of a developing economy because it is capable of demonstrating the physical costs to populations as their economies move through the development process. This distinguishes height from the immediately recognizable

standard of living measure of income. Income paints only a partial picture since it assumes general well being can be inferred from purchasing power alone.

A developing economy should be represented by both material and physical measures: a reflection of both purchasing power and health. The divergence of income and height measures demonstrates the dynamics of this process, as the general rise of incomes over the nineteenth century came at the expense of both health and nutrition and ultimately height. The decline in average height establishes an opportunity to explore the points of departure between height and income measures.

In order to clarify this difference, the idea of convergence is applied to the study of stature. Convergence describes the evolution of average height differences across U.S. states during the nineteenth century. It seeks to clearly define stages of the development path by focusing on the changing magnitude of height differences between short and tall populations. The development path in the present study identifies three stages of the U.S. developing economy as it relates to height: divergence, negative convergence and ultimately positive convergence.

Divergence is evidence of increasing inequality and suggests states with shorter populations are not catching up to states with taller populations. The initial divergence in the early decades of the nineteenth century can be attributed to the urban-rural difference as well as improvements in transportation. Living and working close together increased the possibility of spreading disease in urban populations. As the nutrient source shifted towards processed foods and beverages in urban areas, net nutritional status suffered, leading to diminished height. While the transportation improvements allowed larger segments of the urban population to enjoy a more varied diet, food was less dense in nutrients on arrival and created a new outlet for spreading disease to locations previously isolated from such sicknesses. The divide between urban and rural populations and the expansion of consumption choices afforded by the increase in incomes mark the first stage of development as the gap between short and tall populations is increasing.

Negative absolute convergence implies all states converge to a lower, common steady state level of height with initially taller states, such as Midwestern and Southern states, experiencing larger growth rate declines than the more urban Northeastern states. The height gap between short and tall populations is decreasing. As Southern attention was diverted from food crops to cotton and iron production, net nutritional status was compromised as prices of protein-rich sources such as dairy and meat began to rise and populations began substituting cheaper, more carbohydrate-rich food. The carbohydrate rich diet is less likely to provide the nutrients and protein needed to facilitate growth and contributed to the decline in mean height. The second stage of development reveals the ubiquitous effects of industrialization as it extends its influence to the initially taller, rural populations. As they were previously isolated from industrial activity, their declines in mean height are greater than that of populations that were urban in the early decades of the nineteenth century.

The Midwestern decline in Figure 6 can be partially explained by increasing income inequality stemming from location-specific human capital. Early arrivers knew the strengths and weaknesses of growing specific crops and the best way to farm their existing crops. The knowledge was valuable as they were able to select the best and most fertile land and rapidly accumulate wealth. Their location specific human capital maximized the rents they earned from the land and concentrated wealth to this select group, contributing to the rising wealth and income inequality in this region. The human capital theory is not an exact match geographically and suggests the explanation of the Midwestern decline could be further clarified. The coal industry boom generated negative health externalities. As offensive pollutants were released into the air without concern for health or the environment, growth was inhibited as nutrients were diverted from growth and directed to fighting sickness and disease. The poorest segment of society was unable to move away from the point of pollution and was therefore more susceptible to its effects. The physical effects stemming from the coal boom would have offset any increases in income for

the poor. Increases in income by the wealthy would have done nothing to increase their stature if their growth potential were already reached. Therefore the general increase in income was met with a decline in average height.

The last stage of the development path is positive convergence. The positive convergence at the end of the nineteenth century is the result of the onset of germ theory and improved living conditions. As the body had less demands placed on it by disease and environment, more nutrients were available for growth. The end of the century marked the convergence between economic and biological standard of living measures and suggests income can be used exclusively to describe the economy as it enters a more advanced stage of development.

The standard of living measures offer two distinct and opposite accounts of the nineteenth century U.S. developing economy. The goal is not to drive out the notion of well being inferred from income trends, but to supplement it with information embedded in height data. The evolution of height and its convergence in a developing economy is a reflection of the physical costs associated with increased economic activity and income. In the initial stages of economic development, average heights decline and the difference between short and tall populations increase. As industrialization spreads through the economy, all regions begin to experience its physical effects and initially taller populations begin to decline faster than initially shorter populations. The final development stage indicates the decline of physical cost associated with economic activity as average heights begins to rise and shorter populations begin to catch up with taller populations.

Table 3.1: Real Price Movements of Foods (showing the price of each, relative to all consumer goods and services; 1700 = 1.00)

Year	All foods	Bread	Meat	Butter & cheese	Beer	Sugar	Tea
1795	1.08	1.07	0.92	0.86	0.90	0.98	0.50
1820	1.02	1.00	1.20	0.88	1.00	0.54	0.48
1850	1.00	0.94	1.12	1.07	1.11	0.48	0.41

Source: Clark et al. (1995), "British Food Puzzle".

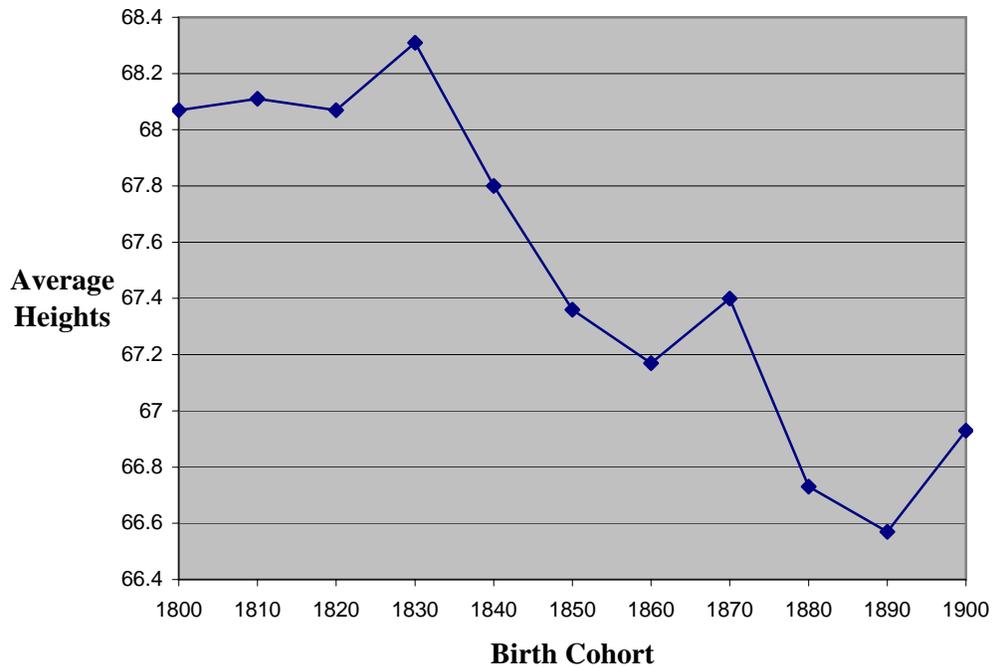


Figure 3.1
U.S. Average Heights: 1800-1900

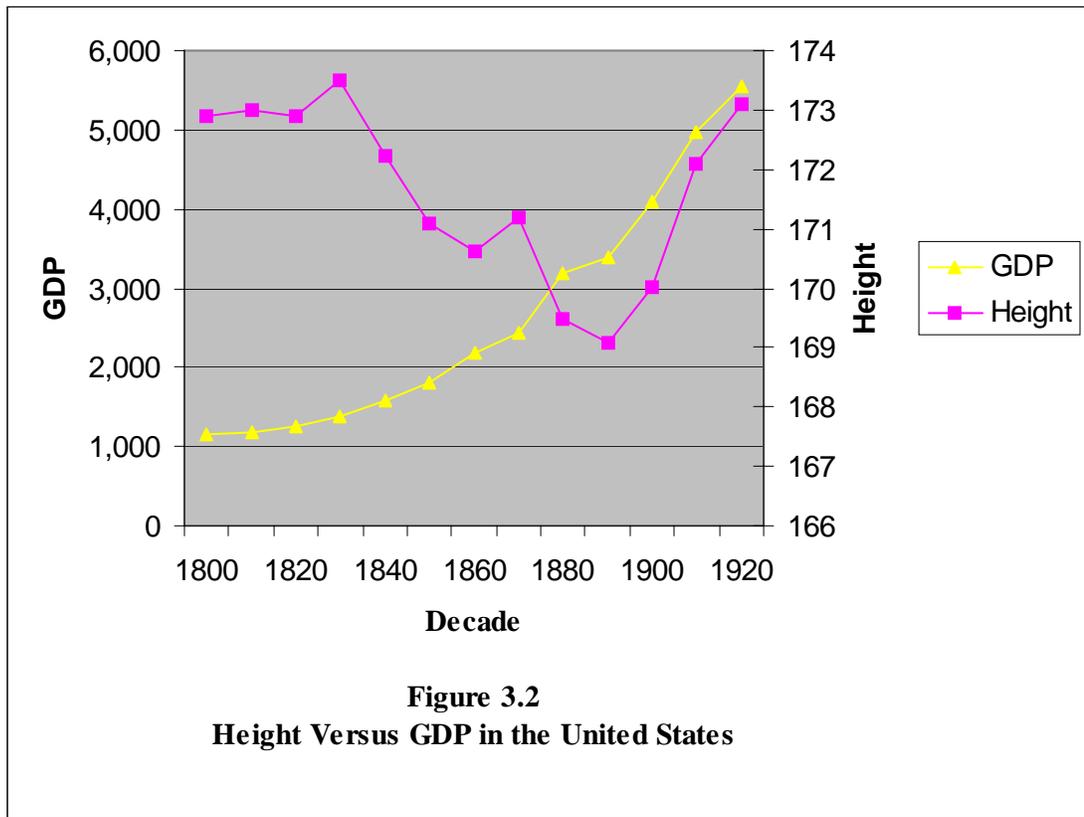


Table 3.2: Comparison of National Average Height Estimates

Year	Weighted Average	U.S. Actual Average	Difference
1800	68.02	68.07	-0.05
1810	67.65	68.11	-0.46
1820	68.02	68.07	-0.05
1830	68.27	68.31	-0.04
1840	67.78	67.80	-0.02
1850	67.37	67.36	0.01
1860	67.09	67.17	-0.08
1870	67.40	67.40	0.00
1880	66.72	66.73	-0.01
1890	66.38	66.57	-0.19
1900	66.15	66.93	-0.78

Source: Steckel, “Stature and the Standard of Living”; Chanda and Craig (2005)

Table 3.3: Absolute Convergence Regression Results
(Dependent Variable, Growth Rate in Average Height)

Absolute Convergence Over 20 Year Periods	Growth Rate 1820-1840	Growth Rate 1830-1850	Growth Rate 1840-1860	Growth Rate 1850-1870	Growth Rate 1860-1880	Growth Rate 1870-1890	Growth Rate 1880-1900
Log of Height 1820	.01164*** (.001619)						
Log of Height 1830		.01151 *** (.002296)					
Log of Height 1840			.00793 * (.004295)				
Log of Height 1850				.03419 *** (.010929)			
Log of Height 1860					.01775 (.013555)		
Log of Height 1870						-.0099*** (.002977)	
Log of Height 1880							-0.0116 (0.003795)
Observations	26	26	26	26	26	26	26
R-Square	0.6496	0.3567	0.0981	0.2041	0.0599	0.2878	0.0068

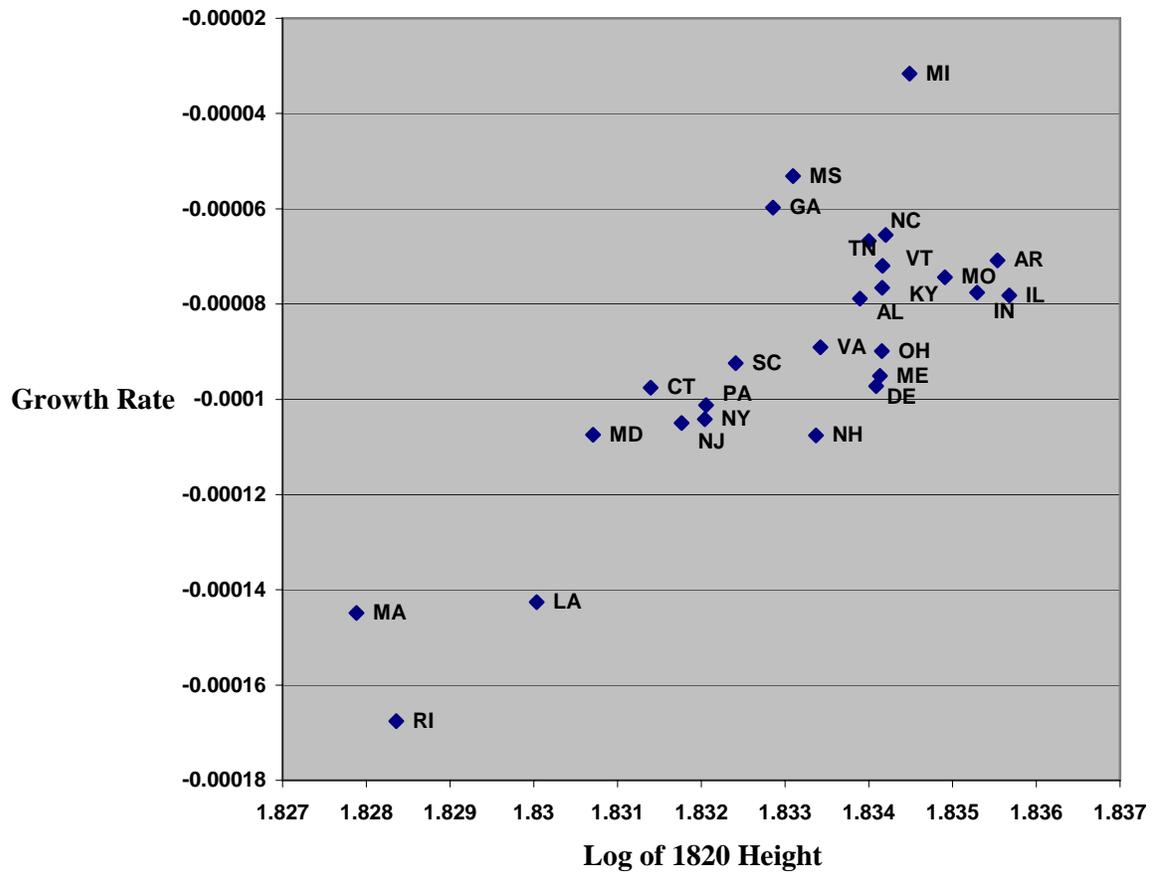


Figure 3.3
Absolute Divergence 1820-1840

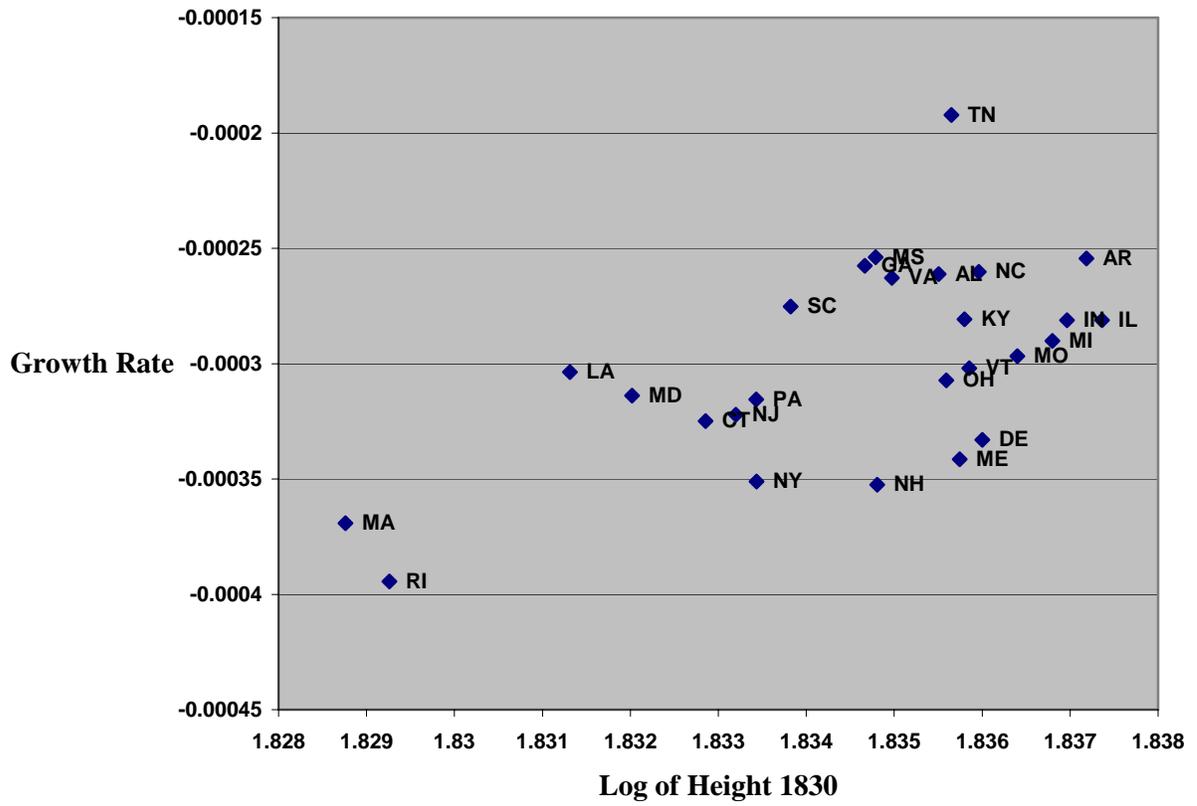


Figure 3.4
Absolute Divergence 1830-1850

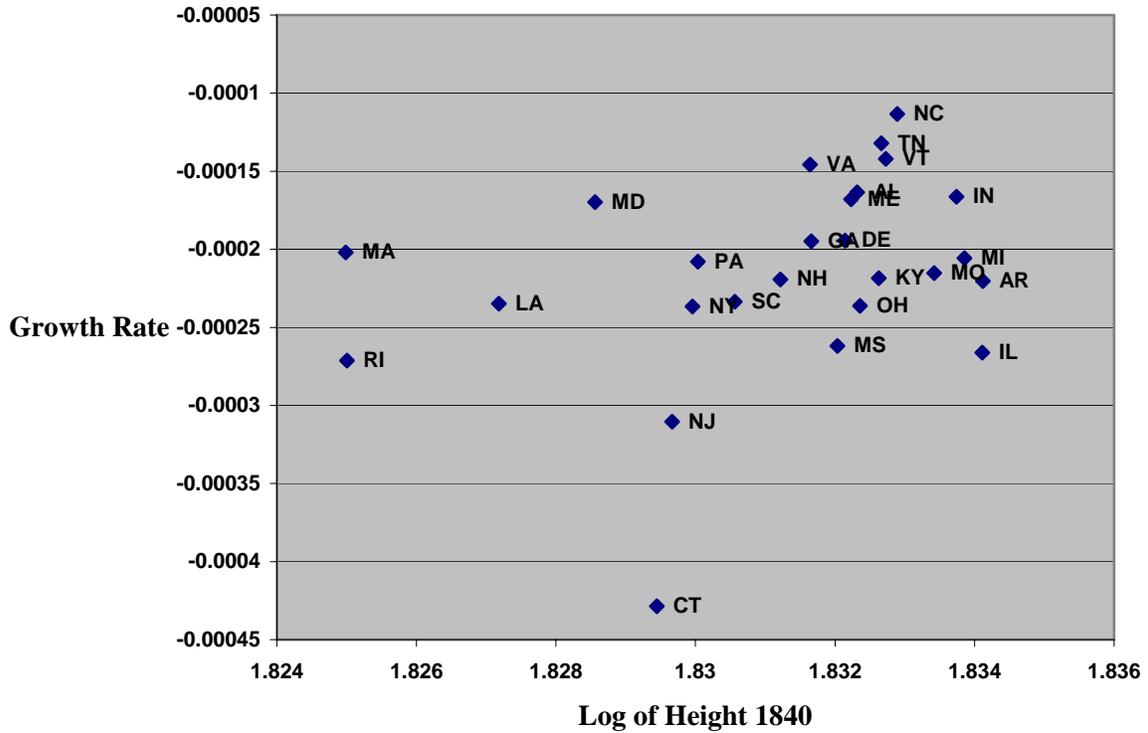


Figure 3.5
Absolute Divergence 1840-1860

Table 3.4: Contrast of Antebellum Income and Height Estimates

Year	Real GDP per Capita (\$1840)	Percentage per annum GDP Growth	U.S. Average Height	Percentage per annum Average Height Growth
1800	78	-	68.07	-
1810	82	0.51	68.11	0.005876
1820	84	0.27	68.07	-0.00587
1830	90	0.72	68.31	0.035258
1840	101	1.13	67.8	-0.07466
1850	111	0.93	67.36	-0.0649
1860	135	1.95	67.17	-0.02821

Source: Weiss, "U.S. Labor Force Estimates" as reported in Haines et al., "The Short and the Dead."

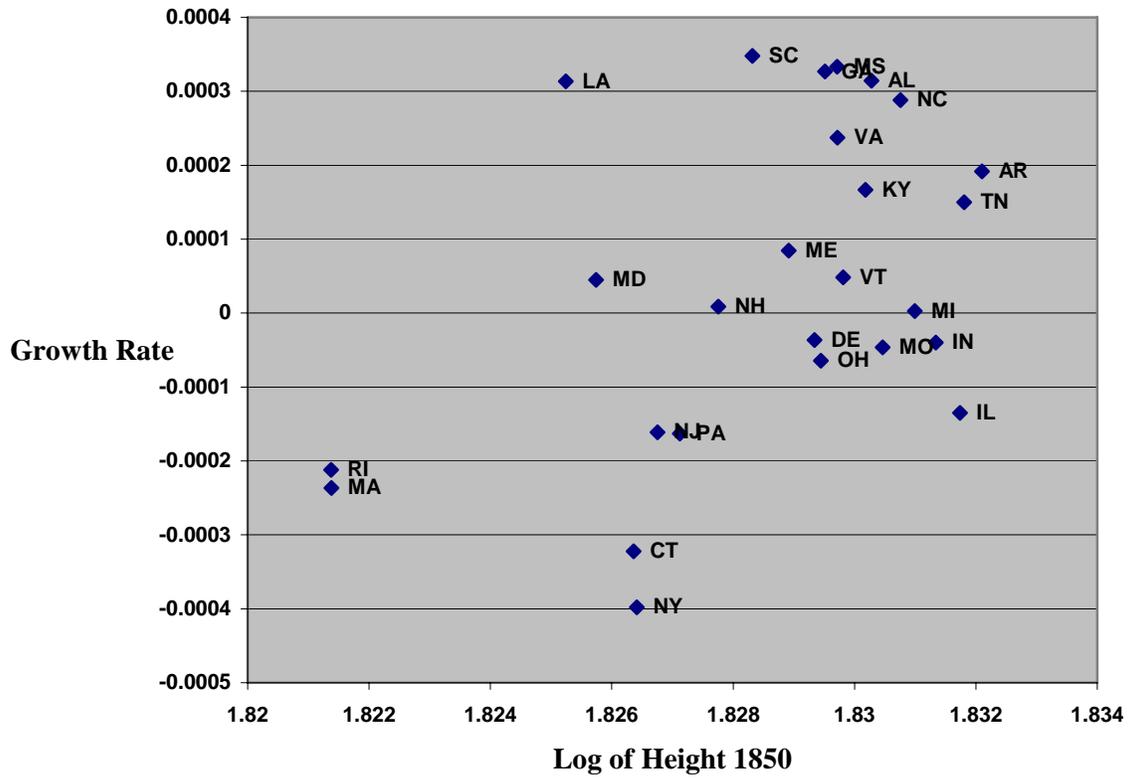


Figure 3.6
Absolute Divergence 1850-1870

Table 3.5: Absolute and Conditional Convergence Regressions

	Conditional Convergence Growth Rate 1860-1880	Absolute Convergence Growth Rate 1860- 1870	Conditional Convergence Growth Rate 1870- 1880	Conditional Convergence Growth Rate 1880-1900
Log of Height in 1860	0.003519 (0.007602)	0.04626* (0.02642)		
Log of Height in 1870			-0.01251* (0.005682)	
Log of Height in 1880				-0.01129*** (0.003609)
Southern Dummy Variable	0.000937** (0.000114)		0.000419** (0.000167)	0.000389*** (0.000106)
Observations	26	26	26	26
R-Square	0.7606	0.11323	0.2245	0.374

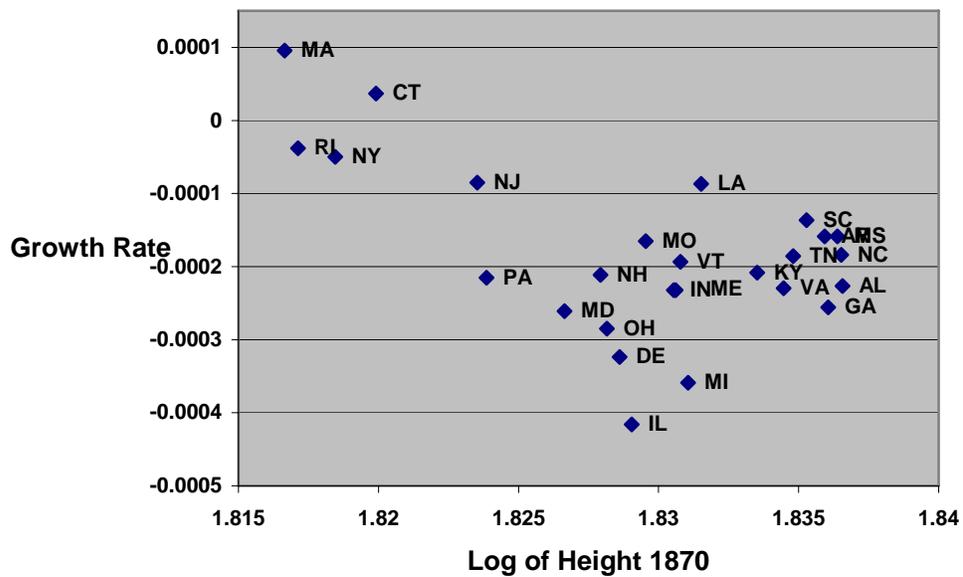


Figure 3.7
Absolute Convergence 1870-1890

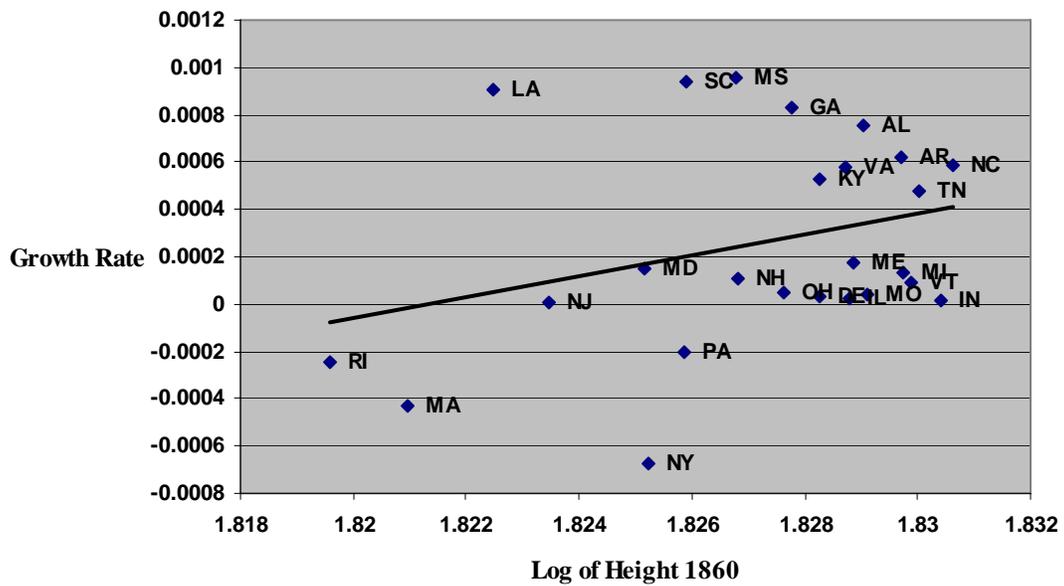


Figure 3.8
Absolute Divergence 1860-1870

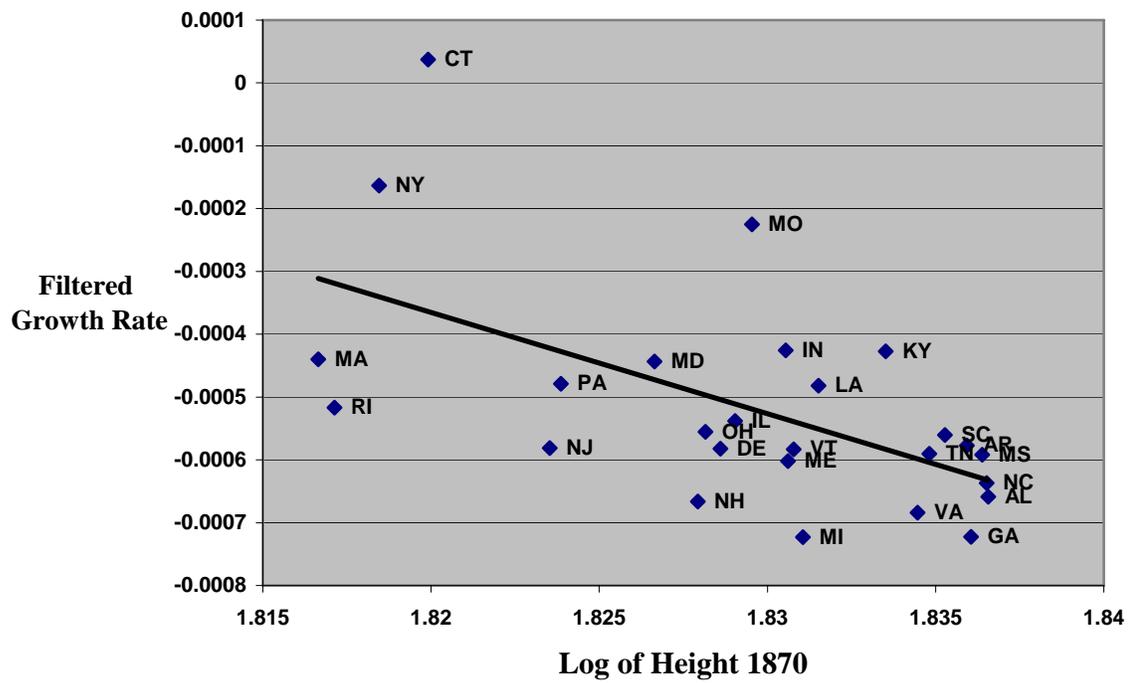


Figure 3.9
Conditional Convergence 1870-1880

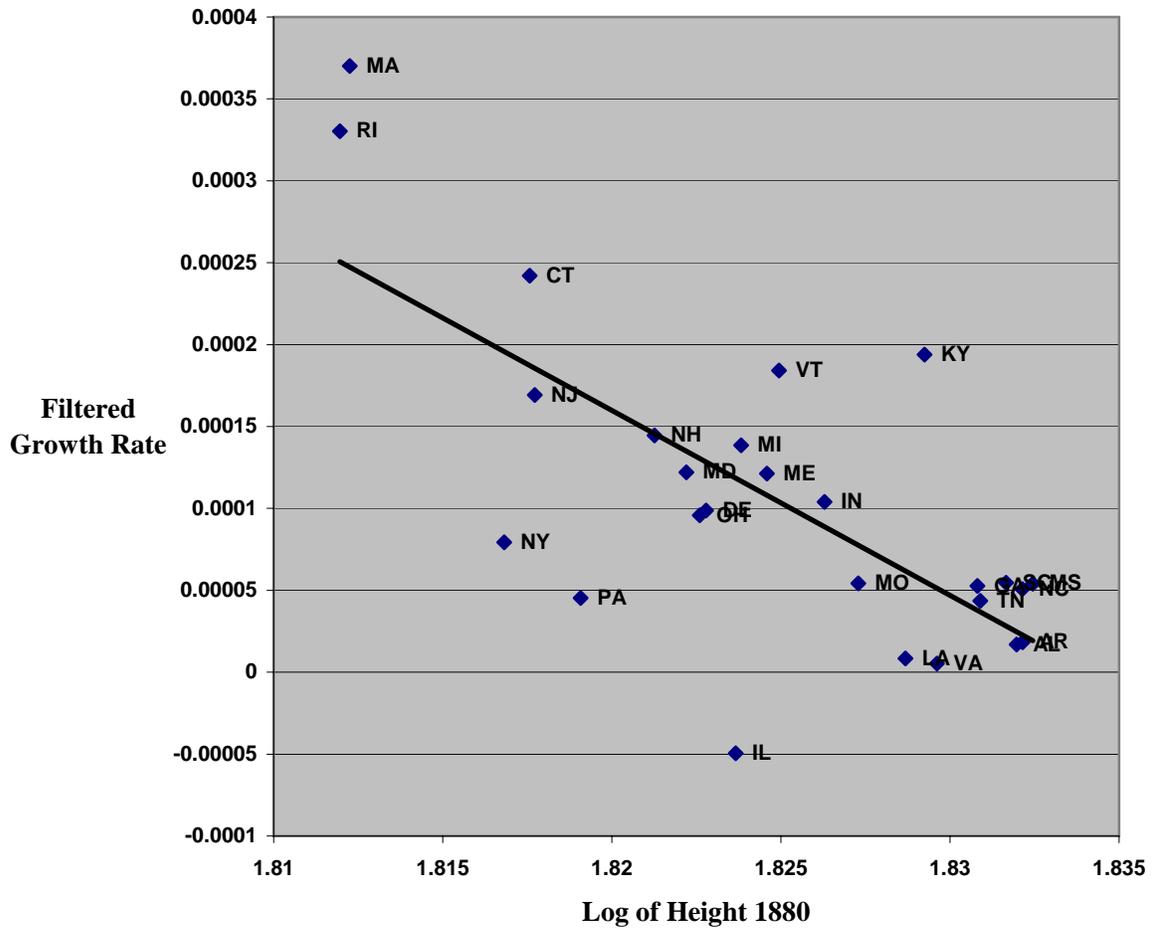


Figure 3.10
Conditional Convergence 1880-1900

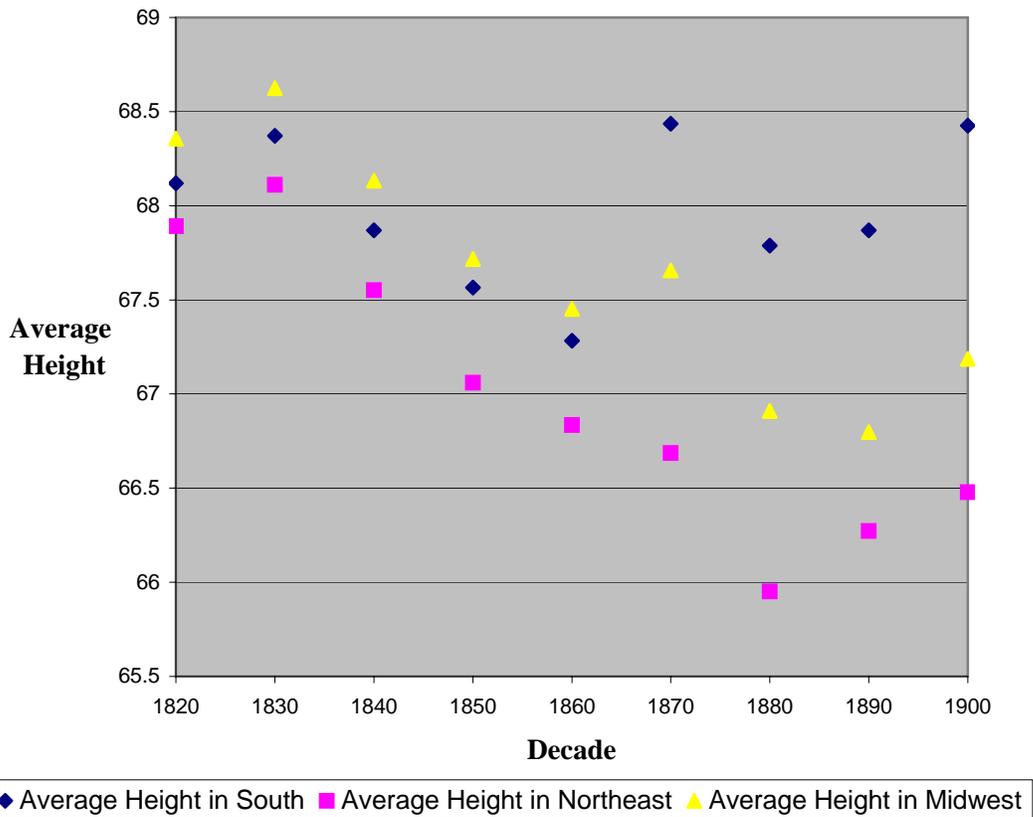


Figure 3.11
Average Height by Region

Table 3.6: Leading Coal Producing States, 1889

State	Coal Production (thousands of tons)
Pennsylvania	81,719
Illinois	12,104
Ohio	9,977
West Virginia	6,232
Iowa	4,095
Alabama	3,573
Indiana	2,845

Source: *Thirteenth Census of the United States, Vol. XI, Mines and Quarries, 1913,*

Table 4, p. 187.

Table 3.7: Conditional Convergence Regressions

(Dependent Variable, Growth Rate in Average Height, 1870-1890)

	Conditional Convergence Growth Rate 1870-1890
Log of Height in 1870	-0.001875*** (0.00336)
Coal Production Per Capita	-0.0026* (0.00138)
Southern Dummy Variable	0.0004163*** (0.000095)
Observations	26
R-Square	0.6649

TABLE 3.8: Increasing Urbanization of the Midwest

State	City	Percentage Increase in Urban Population	1890 Urban Ranking (out of 100 cities)
Illinois	Chicago	367.87%	2
	Peoria	130.94%	71
	Quincy	179.54%	96
Ohio	Cincinnati	137.31%	9
	Cleveland	281.54%	10
	Columbus	281.86%	30
	Toledo	257.83%	34
	Dayton	200.90%	45
Missouri	Saint Louis	145.33%	5
	Kansas City	411.39%	24
	St. Joseph	267.44%	55
Michigan	Detroit	258.71%	15
	Grand Rapids	365.17%	47
Indiana	Indianapolis	218.55%	27
	Evansville	232.51%	56
	Fort Wayne	199.76%	86
Kentucky	Louisville	59.92%	20
	Covington	52.50%	82

4. Chapter 4: Health, Urbanization, and Economic Growth

4.1 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 studies of Sweden, the Habsburg Monarchy, France, and Bavaria in the eighteenth century and the Netherlands, United Kingdom, and United States in the nineteenth century (See for example, 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 as a result of industrialization.

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.⁴⁶ 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 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

⁴⁶ 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.

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).⁴⁷ 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, I 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.

4.2 Height and GDP

The countries used in the analysis are the United States, United Kingdom, Netherlands, France, Sweden, Belgium, Denmark, and Germany, and I 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

⁴⁷ Quarantines would not have been feasible in the United Kingdom, given its proximity and connections to Europe (Baldwin 1999)

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.⁴⁸ (All of the height data measurements are reported in Appendix A.)⁴⁹

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,

⁴⁸ A height puzzle was observed in France in the eighteenth century.

⁴⁹ Height data were only available for five decades in Germany and the figures are shown in Appendix A.

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.

4.3 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. I employ regression analysis to determine the effects of each variable 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.

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 4.1 shows intercepts and urbanization and GDP slopes that vary by country.

$$\text{Height}_{it} = \beta_1 + \beta_2 \text{DeathRate}_{it} + \beta_3 \text{Urbanization}_{it} + \beta_4 \text{GDP}_{it} + \beta_5 \text{Transportation}_{it} + \beta_6 \text{Water}_{it} + \beta_7 (\text{GDP}_{it} * \gamma_i) + \beta_8 (\text{Urbanization}_{it} * \gamma_i) + \gamma_i + \varphi_t + \beta_9 \text{CoalProduction}_{it} + e_{it} \quad (\text{Equation 4.1})$$

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. They were lowest in the United States and Sweden, and highest in the Netherlands and the United Kingdom.⁵⁰ By the twentieth century, the United States had experienced an increase in urbanization of 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

⁵⁰ See Appendix A for urbanization data by country.

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. In other words, there is uncertainty as to whether the urbanization effect will be significantly different from zero in the Netherlands. 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, 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.⁵¹ 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.

⁵¹ See Appendix A for a lengthy discussion of the relevance of the variable and how the decade was selected for each country.

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 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 I 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? I 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 1870-1890.⁵² 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.⁵³ Coal workers were more prone to suffer from consistent smoke inhalation and acute respiratory disease. Among the poorest segment of society, increased environmental pollution

⁵² See Chapter 3 above.

⁵³ Especially carbon dioxide, as it is one of the five major greenhouse gases contributing to the greenhouse effect.

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.

4.4 Results

Table 1 reports the results of two regression models based on Equation 4.1.⁵⁴ 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 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

⁵⁴ 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.

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 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 are 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.⁵⁵ 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 since the body does not have to work as hard to stay warm. This would be especially true in colder environments.⁵⁶

4.4.1 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

⁵⁵ Assuming they are not importing more than they export.

⁵⁶ 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.

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 4.2 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 4.2 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 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 grew significantly 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.⁵⁷

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.

4.4.2 GDP interaction variables

The estimated country GDP effects are reported in column 1 of Table 4.2 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 4.2 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,

⁵⁷ 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 appears to have impacted height the least in Belgium 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 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.

4.5 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. In other words, I find evidence to support 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 and 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 4.1 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 4.2.

*** Denotes significance at the 1 percent level.

** Denotes significance at the 5 percent level.

*Denotes significance at the 10 percent level.

Table 4.2: Net Effects of GDP and Urbanization on Height by Country

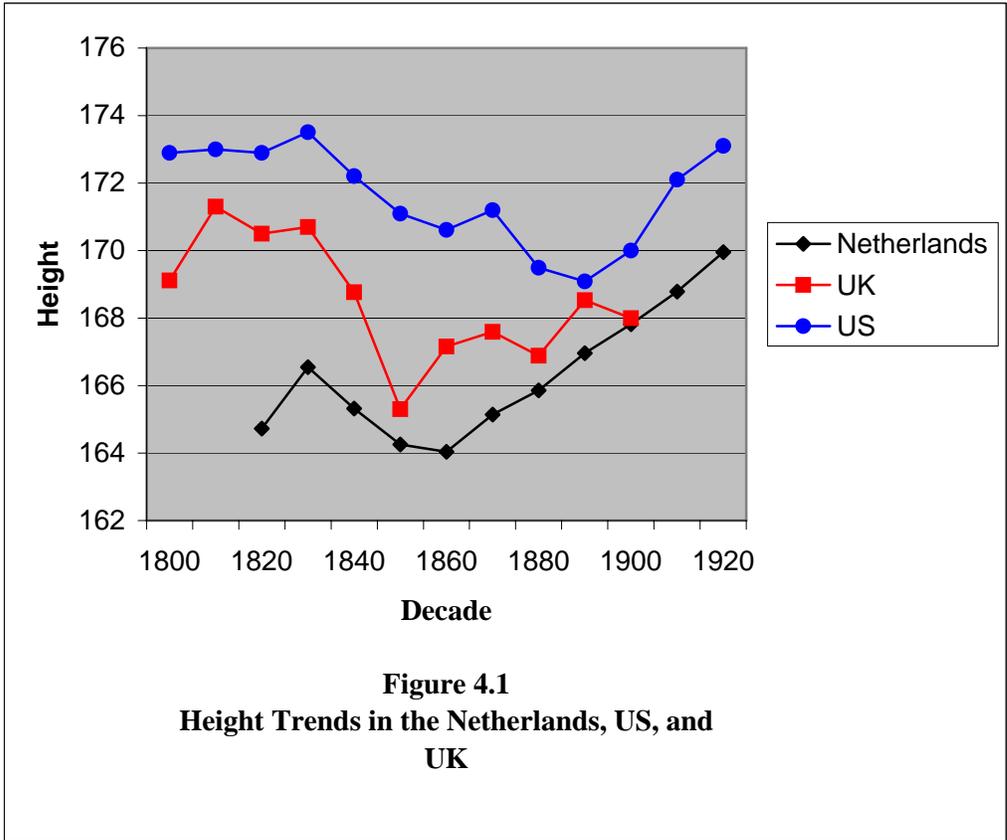
Country	GDP 1		Urbanization 2	
	Estimate	Approx Std Error	Estimate	Approx Std Error
US	-0.0021**	0.0007	-0.1269*	0.0544
UK	0.0015**	0.0005	-0.3529***	0.0466
Sweden	-0.0001	0.0013	0.1272	0.1128
France	0.0002	0.0015	-0.0964	0.1192
Netherlands	0.0025**	0.0010	-0.2500*	0.1200
Belgium	-0.0037**	0.0015	0.4393*	0.1605
Germany	-0.0053	0.0029	-0.0053	0.0029
Denmark	-0.0017	0.0021	0.1480	0.1741

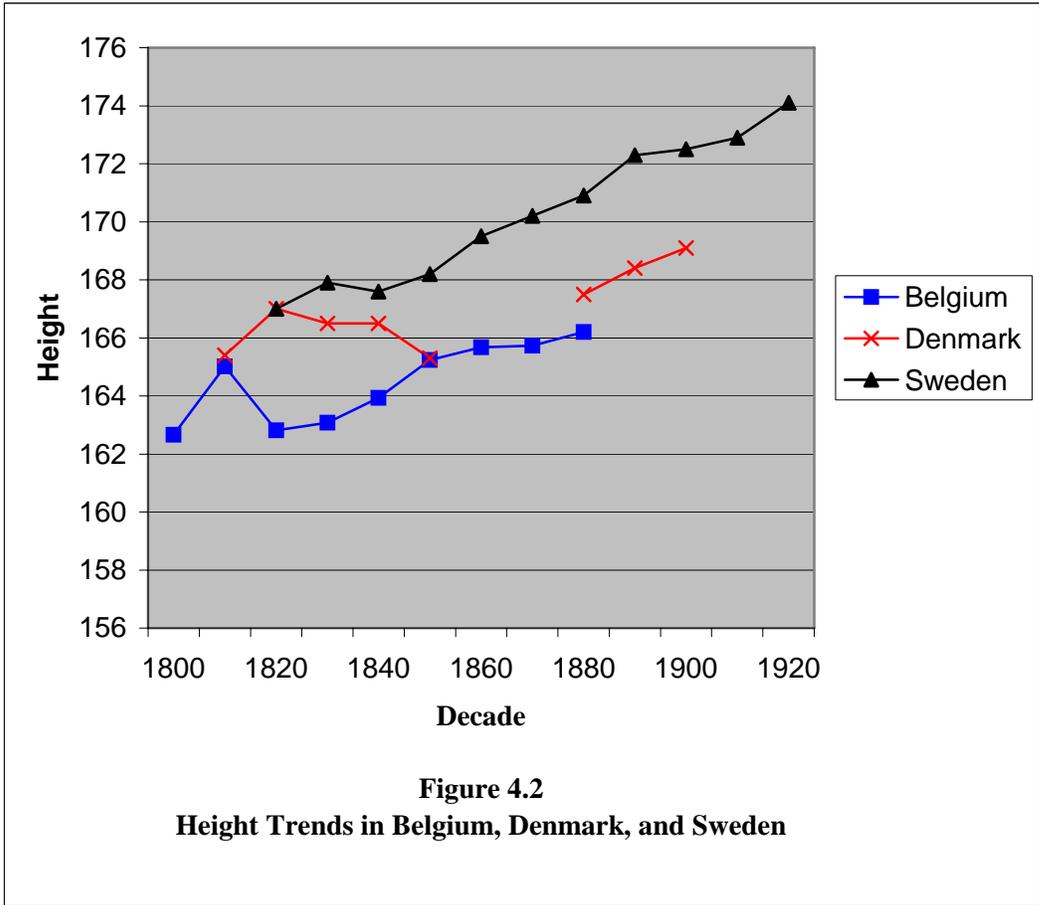
Notes: Entries for each country were calculated by summing coefficients; standard errors were calculated as $[\text{var}(\beta_i) + \text{var}(\beta_j) + 2\text{cov}(\beta_i, \beta_j)]^{1/2}$.

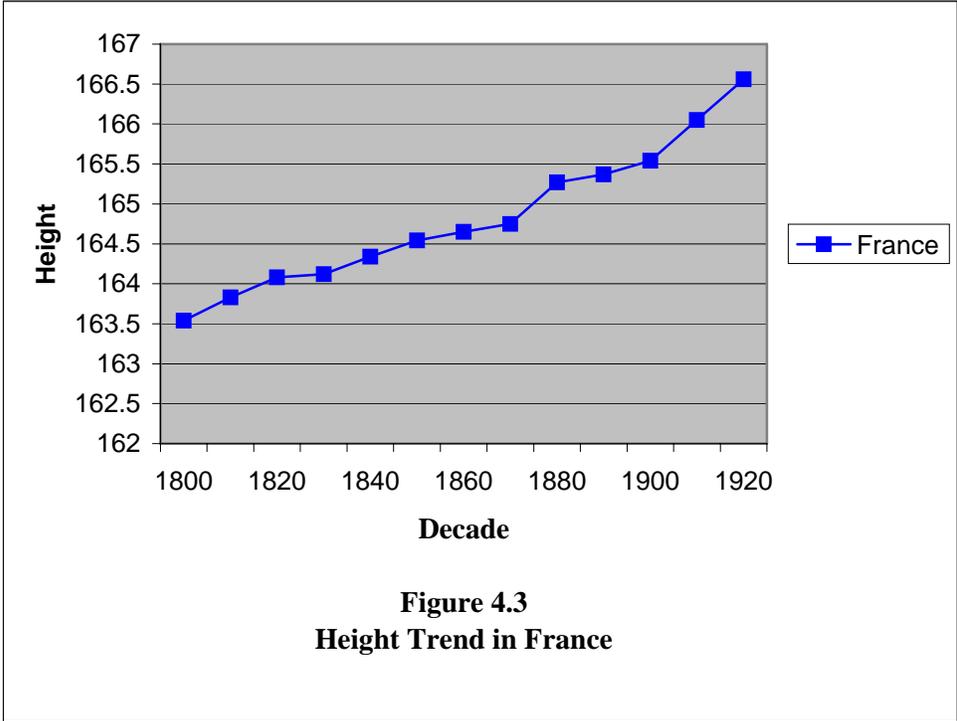
*** Denotes significance at the 1 percent level.

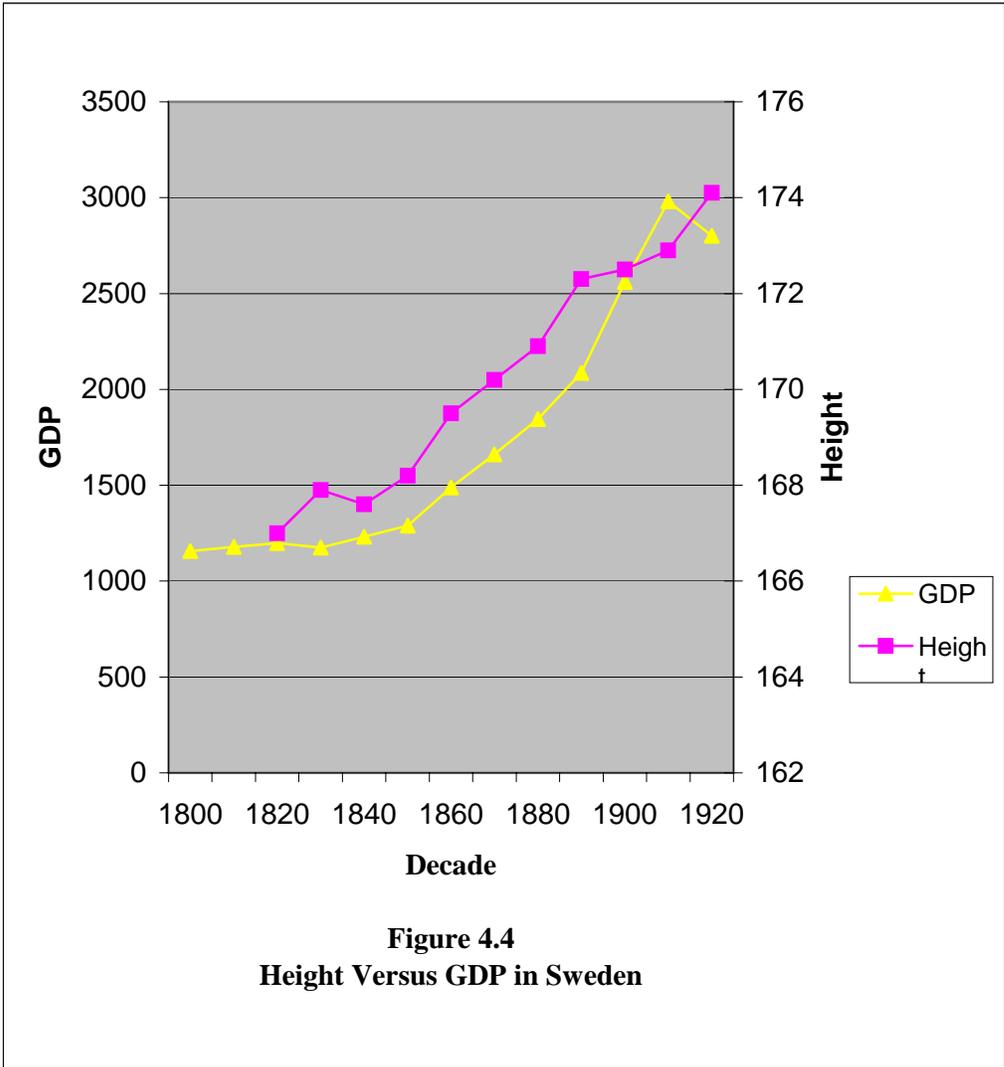
** Denotes significance at the 5 percent level.

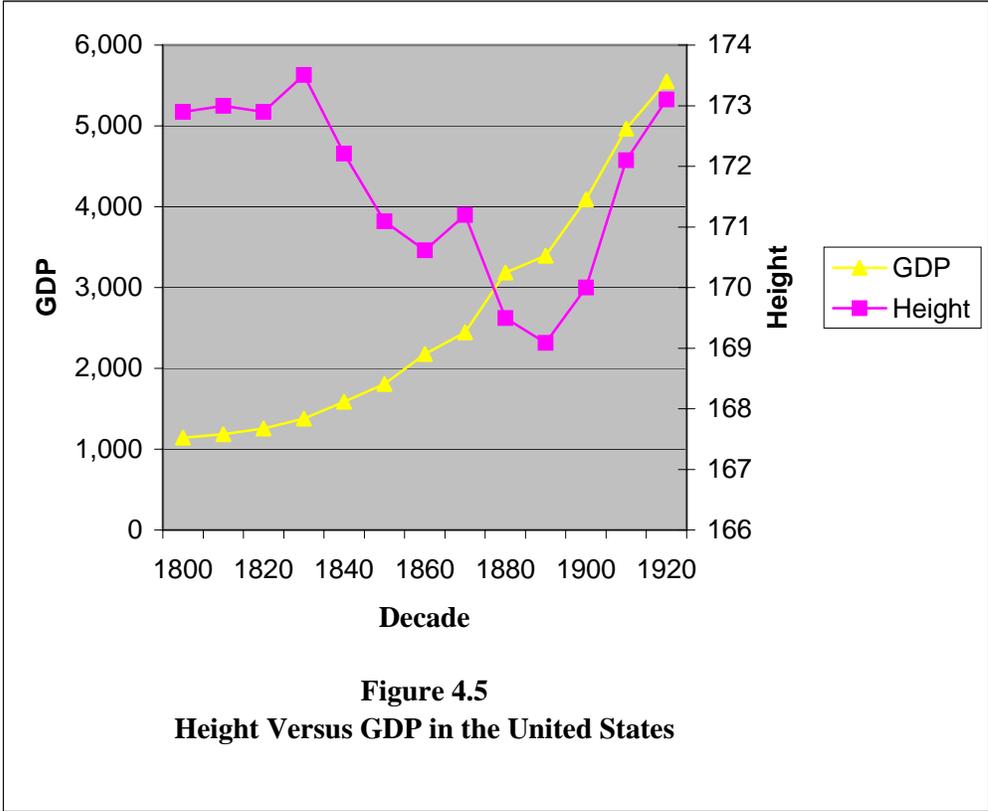
* Denotes significance at the 10 percent level.

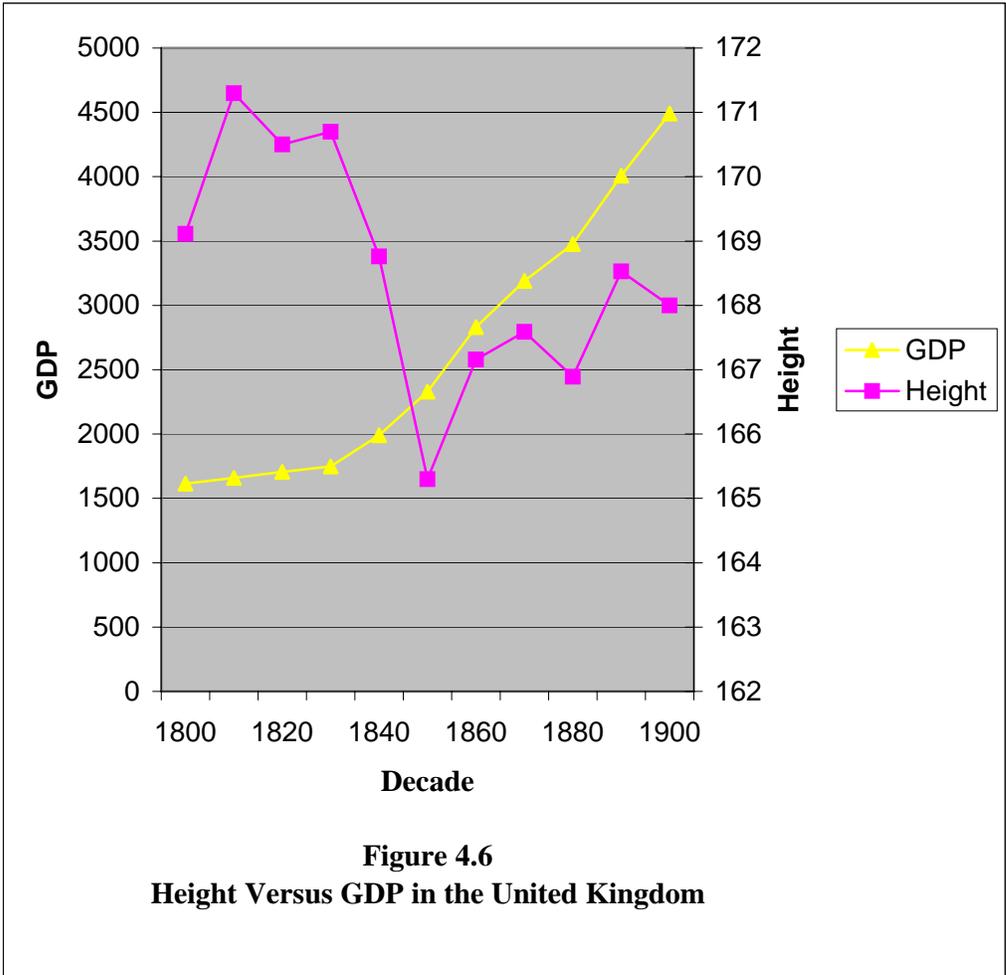


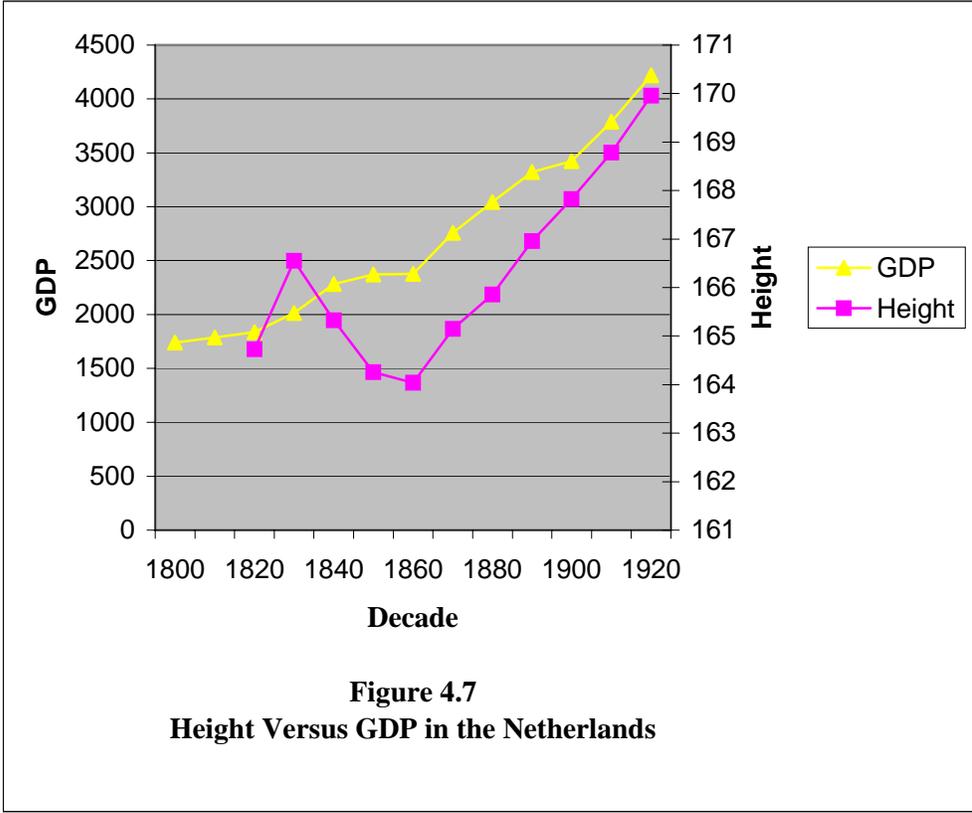


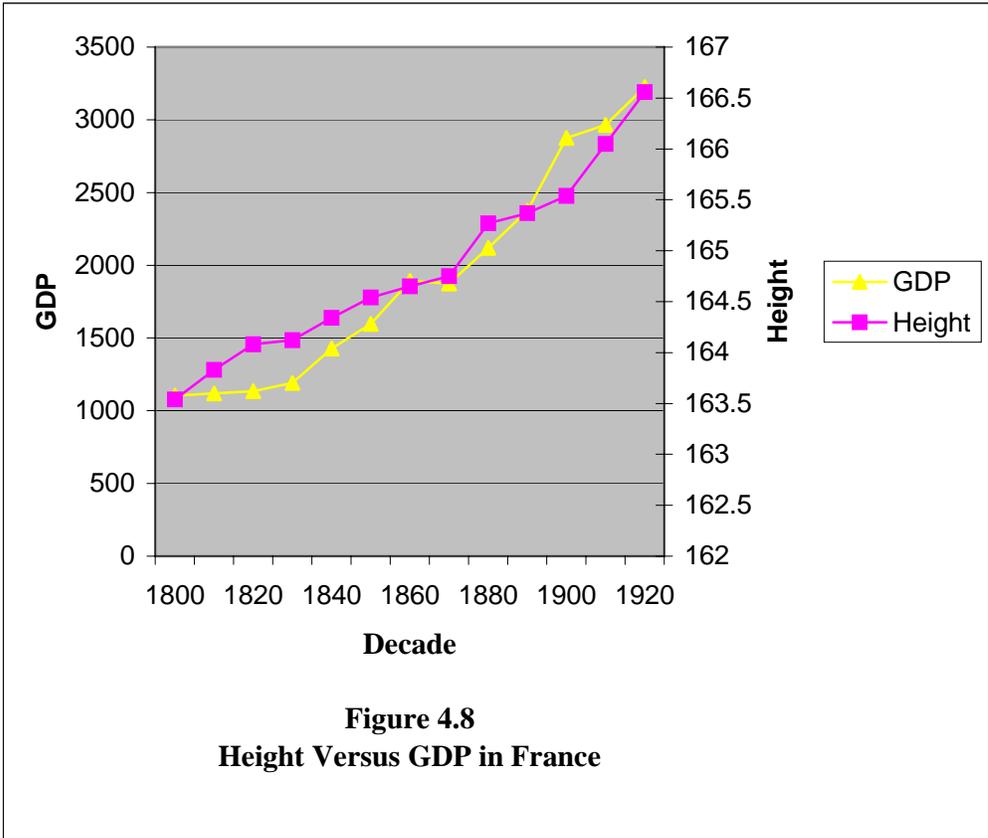


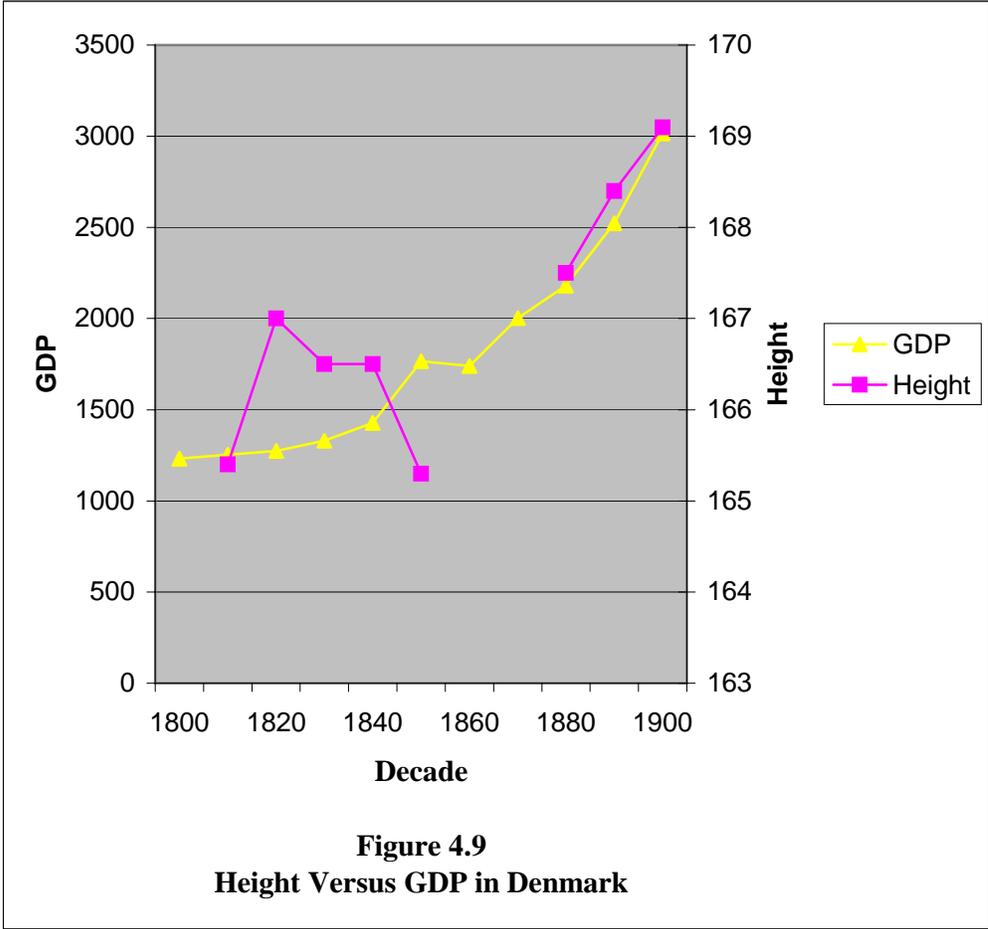


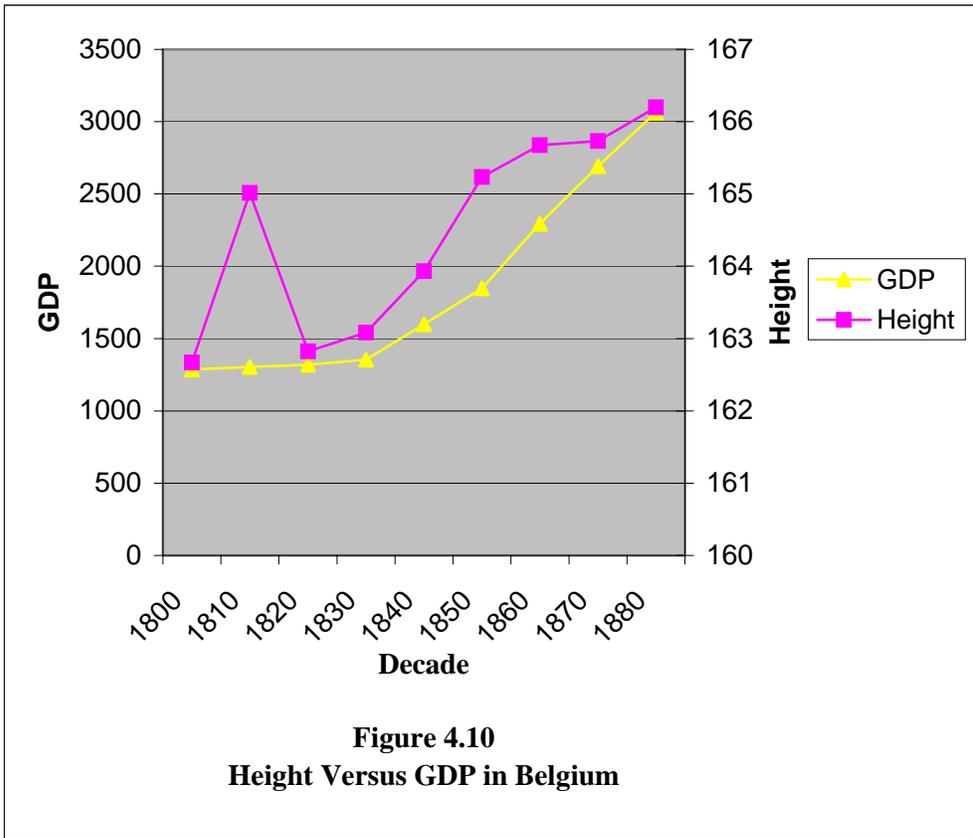












5. Conclusion

Although most research on the standard of living has focused primarily on income, it is important to remember that income cannot capture all of the effects of economic activity. Several studies have identified periods of simultaneous economic growth and human stature declines, implying that the general rise of incomes came at the expense of both health and nutrition and ultimately height. Increased economic activity can be detrimental to a population's health, through environmental changes, which include nutrition, work intensity, and exposure to disease. Biological measures of the standard of living, such as stature, reflect these environmental changes and should be considered when describing economic performance and the well being of a population. Since economic activity can diminish a population's health status, the standard economic measures of the living standard should be balanced with biological indicators, such as stature, a variable capable of tracking changes in health.

While the use of stature as an economic variable is still relatively new, it is a useful addition to an economist's vocabulary. While income measures, such as gross domestic product, dominate the literature, stature can be helpful in many situations. The typical concern relating to the use of stature is whether fluctuations in average height are simply the result of genetics. While an individual's genes may determine adult height *potential*, whether that potential is realized or not depends on the economic and disease environment in which the individual matures (Tanner 1978; Thoday 1965). Changes in the environment will be the driving force behind changes in average height, since genetic differences across individuals – i.e. divergence from the mean - approximately cancel in averages across populations.

In this dissertation, I first use stature to approximate income. While the U.S. census has undergone an impressive evolution to reach its current form, early censuses do not

provide enough information to estimate per capita income, and there is no universally accepted set of income figures before 1834. In Chapter 2 I employ stature to estimate protein production in the eighteenth-century United States. The protein estimates are then assigned a dollar value and converted to an estimate of GDP. While many studies have placed economic growth (as measured by GDP per capita) in the range of 0.3 to 0.6 percent per year in the eighteenth century, some have suggested rates as high as one percent (George Rogers Taylor 1964) and as low as almost zero (Mancall and Weiss 1999).

Results from this chapter suggest an average annual rate of change of approximately 1.2 percent per year over the first half of the century, which is considerably higher than other estimates. The fluctuations between periods suggest growth swings as high as six percent in certain sub periods. One implication of the large growth swings is that the colonial American economy may be more similar to European economies than previously thought, as they are in line with European business cycles in the eighteenth century (Craig and Fisher 2000, and Craig and Garcia-Iglesias 2006).

My findings suggest that GDP per capita rises until 1724, reaches its lowest point in 1730, and rebounds until 1750. GDP per capita estimates for the 1700-1720 time period range from \$850 to \$1,000 (in 1990 dollars) and coincide with several existing estimates, including that of Jones (1980), McCusker and Menard (1985), and Mancall and Weiss (1999). Therefore the higher growth rate result obtained in this chapter is a result of a higher 1750 estimate than other studies. Since the 1750 estimate suggests an income level very similar to estimates in 1776, it is possible that there was no growth or even negative growth from 1750 to 1776. Mancall and Weiss found a decrease in the growth rate of 0.02 percent per year from 1750 to 1770. The results uncover new fluctuations in economic activity and offer a more optimistic view of economic

growth in colonial times, and they suggest the economic impact of the Seven Years War and its aftermath were more negative than previously supposed.

Chapter 3 focuses on the regional growth pattern of height in the nineteenth-century United States, exploring the welfare implications associated with the convergence of height as reflected by the gap between short and tall populations. While income steadily rose over the century, albeit with fluctuations around the trend, height did not follow this unidirectional pattern. Stature rose early in the century, fell mid-century, and rose again at the end of the century.

Evidence of groups of economies moving towards their biological height bounds suggests improvements in human welfare. One way to assess whether a society is moving towards its biological height bound is to test for the presence of convergence, or whether initially shorter populations have higher growth rates than those experienced by taller populations.⁵⁸ Using a data set consisting of mean adult stature for native-born white males in ten-year intervals from 1800 to 1900, the analysis tests for convergence (Barro 1991) of height among states.

This chapter highlights a development path that identifies three periods of the U.S. economy as it relates to height: divergence, negative convergence and ultimately positive convergence. The evolution of height and its convergence in a developing economy is a reflection of the physiological costs associated with increased economic activity and income. In the initial stages of development, average heights decline the most in the centers of modern economic activity, as economic expansion imposes significant physical costs on the human body and pushes this part of society away from its biological height potential. As industrialization spreads through the economy, all regions begin to experience its physical effects as heights in the newly industrialized parts of the economy begin to decline faster than the segment of population

⁵⁸ As improvements in environment, medical care associated with the germ theory, and nutrition become available to broader segments of society, the growth rate of stature would be lower for the taller populations, as they are closer to their biological bound than the shorter populations.

in the center of the initial transformation. In a contemporary sense, developing economies should be sensitive to the negative externalities generated by growth's economic expansion, implying that significant attention should be devoted to adopting measures that minimize the physiological costs incurred by populations. The final development stage indicates the decline of physiological costs associated with economic activity as average heights begin to rise and population move towards their biological height bound.

Chapter 4 expands the focus from height in the United States economy to height in the global economy. Recent debate, including that between Deaton (2006) and Fogel (2004), concerning the relative impacts of economic growth and public health measure taken in response to the germ theory, suggest a cross-country experiment testing the contribution of each. 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 early developing countries, but also currently developing ones. This chapter uses death rates, GDP, urbanization, water supply quality, coal production and railway mileage to study the evolution of height in a cross-section of countries from 1800 to 1920.

While previous studies have used country-level studies to document changes in height, no study has made an empirical statement on the global significance of the determinants of height. I construct a "global water supply variable", which is the first of its kind, and I test whether securing healthy water supplies significantly affected height. I find the impact was positive and significant, giving empirical support to the role of public health measures in the debate on the causes of improvement in nineteenth century health. As expected, the results suggest that death rates were consistently and negatively related to stature. Coal production (a proxy for industrialization) significantly and positively affected stature, evidently serving as a proxy for economic growth and overwhelming the negative externalities generally thought to accompany the practice.

Urbanization effects varied by country, implying that the “urban height penalty,” or lower average heights observed in urban areas, was not present in all countries. The GDP effect also varies by country and in fact, GDP and height were negatively correlated in several countries. 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.

The nineteenth century was marked by the spread of industrialization and urbanization. As health issues became a public concern, the end of the century saw great improvements in public health, medical research, and technology. Since height is an important economic variable, identifying its determinants is necessary. Chapter Four makes a statement regarding the impact of economic and health variables on stature in the nineteenth century United States as well as parts of Europe, offering a broader picture of what affected height over the period 1800-1920. My findings support the view that both measures of growth and public health positively influenced the biological standard of living.

My future research plans include exploring how important – in a macro context - coal production was to productivity growth in the American economy in the nineteenth and early twentieth centuries. Was the tremendous coal expansion the result of factors external to the industry, such as increased demands for coal from increasing numbers of consumers, higher incomes, or declining transport costs? Or could the coal expansion be the result of significant productivity growth through improvements in the technological innovations in mining?

A second research project relates to changing consumption bundles as a result of industrialization and economic growth. Alcohol, sugar, and tobacco consumption all increased,

and their effect on height during the nineteenth century United States must be estimated. Heavy alcohol consumption may interfere directly with cellular growth and metabolism, and if a pregnant woman consumes alcohol, it is carried to her organs and tissues including the placenta. The result is a birth defect characterized by growth retardation and malformations of other organ systems.

A third topic relates to climatic fluctuations in a state-level height study of the United States. Height can vary with geography. Biology suggests that animals in cold climates tend to have larger bodies and shorter limbs than those in warm climates. But in industrialized economies, climate fluctuations do not affect height. For instance, Swedes should be short and stocky, yet they are among the tallest people in the world. Mexicans should be tall and slender, but they are plagued by poor diet and disease and their growth is stunted as a result. The nineteenth-century, U.S. climate data project provides temperature, precipitation, and drought variations throughout the United States. These data would indicate whether climate significantly affected height or at what point the economy was industrialized to the point that climate ceased to influence height.

A fourth and completely unrelated topic to my dissertation looks at the role tabloids, such as *US Weekly* or *In Touch* magazine, play in box office revenues. These magazines attract millions of readers a year and yet their impact on the movie industry has not been examined. While these magazines are not read for the accuracy of their information, people form opinions based on the content of the magazine. Do movie stars appearing in these magazines prior to the movie premier increase box office revenues? Does it matter whether the movie star is portrayed in a negative or positive light? For instance, the study may reveal that negative tabloid coverage of Tom Cruise played a role in Cruise's lowest box office opening for the Mission Impossible series with 2006's *MI3*. Then again, although the tabloids made Paris Hilton a star, their coverage did not draw audiences to her Summer 2004 bomb *House of Wax*. Answers to these

questions will determine whether the magazines have a significant impact on the number of movie tickets sold or whether the magazines are read simply for their entertainment value.

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7. Appendix

7.1 Description of the Data

Table 7.1
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 7.2

Percentage of the Population Residing in Urban Areas for Individual Countries

Decade	Belgium	Denmark	France	Germany	Netherlands	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 7.3
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 7.4

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 Misérables* 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.⁵⁹

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.⁶⁰

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 (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

⁵⁹ http://www.makingcitieswork.org/urbanThemes/Urban_Health/Urban_Environmental_Health

⁶⁰ Baldwin (1999), page 63.

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.⁶¹

⁶¹ 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.

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 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.

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 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).⁶²

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.

⁶² This was mainly concentrated in urban areas.

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.

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.⁶³ 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

⁶³ In fact, 19 out of 100 births in Denmark were in Copenhagen as of 1900.
<http://64.233.161.104/search?q=cache:C6K9mKlmHQJ:www.greatestcities.com/Europe/Denmark.html+nineteenth+century+population+copenhagen,+denmark&hl=en&gl=us&ct=clnk&cd=7>

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).⁶⁴

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

⁶⁴ Incomplete refers to the fact that men were still handling human waste.

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

Table 7.5
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.