Height, income, and nutrition in the Netherlands: 
the second half of the 19th century

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Abstract

This paper explores the relationship between height and its determinants, paying explicit attention to the dynamic nature of the velocity of the growth profile. The relationship between height and some measures of income and nutrition is characterized by a changing lag pattern in 19th century the Netherlands.

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1. Introduction

Human physical stature as a measure of living standards has attracted considerable attention because it is influenced by real income, labour intensity, morbidity and nutrition, improvements in dietary intake, public sanitation, and medical technology (Tanner, 1981; Komlos, 1985, 1989; Floud et al., 1990; Steckel, 1995).

This paper explores the dynamic aspects of the relationship between height and two explanatory variables: real income and nutrition. While there are many studies on the effect of income on height (Brinkman et al., 1988; Coll, 1998; Craig and Weiss, 1998; Haines, 1998; Mosk, 1996; Baten, 2000; Baten and Murray, 2000) the extent to which the time profile of income or nutritional intake affects attained height has not been adequately addressed in
the literature, not even in the medical literature. Until reaching final height in adulthood, growth at a particular age is determined by the economic and environmental circumstances up to that age, given the growth potential of the individual. Hence, height at any age is given by the sum of height increments (growth velocity) up to that age. Consequently, height at age \( t \) is a function of the determinants of height between ages 0 and \( t \), prior to adulthood. Thus, the lagged values of the determinants of height determine the current value of height (Komlos, 1989, Chapter 3). Empirical studies tend to adopt a fixed lag scheme for the determinants of height, i.e. assume that the growth velocity does not change over time. However, there is ample evidence that the shape of the velocity curve of growth changes over time (van Wieringen, 1972; Ljung et al., 1974; Komlos, 1989; Eveleth and Tanner, 1990; Hermanussen, 1997; Wit et al., 1999; Fredriks et al., 2000).

We derive a dynamic model of height starting from the identity that the measured heights are the sum of the height increments of the years from birth onwards. We assume that height increments of a given year are influenced by ‘environmental’ circumstances, such as income or nutrition, of that year. The resulting model has a lag pattern that may change over time. Unfortunately, this model cannot be estimated and tested with aggregate data in which we have only one observation on height for each period. Ideally, we need information on the complete growth profile, such as the Stuttgart schoolboys sample described in Komlos et al. (1992).

Therefore, rather than estimating an econometric model of height we illustrate the change in the lag pattern of the determinants of height, the independent variables, in an indirect way by means of bivariate correlation analysis. To avoid spurious correlation between trended series, we follow Woitek (2003) and calculate cycle components (i.e., deviations from trend) of recently published series on 19th century height, income and nutrition in the Netherlands. Whereas, Woitek uses spectral analysis to investigate cycle components, we apply more conventional correlations to bring to the fore the evolving dynamic relationship between height and the explanatory variables. 3D-plots of correlations coefficients between the cycle components of height and the (lagged) cycle components in GDP per capita and nutrition over a moving 31-year window reveal the change in the lag pattern.

The remainder of the paper is structured as follows. The next section presents the growth velocity and cites some evidence from the literature why this curve is time-variant. Section 3 derives our empirical model of height. Section 4 describes the method we use to illustrate the changing lag pattern in the relationship between height and income and nutrition measures. Section 5 presents the data we use in our empirical illustration. Section 6 shows and discusses our empirical results. Section 7 concludes.

2. Growth velocity

Two periods of intense activity characterize the growth process following birth (Tanner, 1989). The change of height is greatest during infancy, falls sharply, and then declines irregularly into the childhood years. During adolescence velocity rises sharply to a peak that equals approximately one-half of the velocity during infancy, then declines rapidly and reaches zero in adulthood. The thick line in Fig. 1 represents a stylized velocity curve, i.e., the derivative of the growth curve.
As can be seen from the figure, young children and adolescents are particularly susceptible to environmental conditions. The return of adequate nutrition following a period of temporary deprivation may restore normal length through catch-up growth. If conditions are inadequate for catch-up, individuals may approach normal adult height by an extension of the growing period by as long as several years. The solid line in Fig. 1 illustrates this. The figure further shows the importance and the sensitivity of the age of measurement. Individuals measured at the age of 20 instead of 19 may easily gain an additional 2–3 cm in height, cf. Section 5.

3. A model of human growth

Let $H^\tau_t$ be the average height of conscripts at age $\tau$ of the cohort measured in year $t$, which is observed from $t = 1, \ldots, T$. The attained height at age $\tau$ is by definition equal to the increments in stature from the year of birth:

$$H^\tau_t = \Delta H^\tau_t + \Delta H^{\tau-1}_t + \cdots + \Delta H^{1}_t + \Delta H^{0}_t,$$

(1)

where $\Delta H^{\tau-i}_t \equiv H^{\tau-i}_t - H^{\tau-i-1}_t$ is the increment in height of the cohort of conscripts measured in year $t$ between age $\tau - i$ and $\tau - i - 1$, $i = 1, \ldots, \tau$ and $\Delta H^{0}_t (\equiv H^{0}_t)$ is the length at birth. For sake of simplicity, we assume that the (unobserved) increments in height depend linearly on income $Y_t$, say, or

$$\Delta H^{\tau-i}_t = \alpha_t Y_{t-i} + \varepsilon_{t-i},$$

(2)

where $\varepsilon_{t-i}$ is an error term and $\alpha_t$ is a time-variant coefficient. Of course, the framework can be extended easily to allow for other determinants of height or more than one explanatory
variable. Substituting Eq. (2) into (1) gives:

\[ H^*_t = \sum_{i=0}^{\tau} \alpha_t Y_{t-i} + \sum_{i=0}^{\tau} \varepsilon_{t-i} = \alpha_t(L)Y_t + \varepsilon_t, \tag{3} \]

where \( L \) is the lag operator \( LY_t = Y_{t-1} \), and \( \varepsilon_t = \sum_{i=0}^{\tau} \varepsilon_{t-i} \) a moving average error expression. The matrix polynomial \( \alpha_t(L) \) captures the velocity of growth: \( \alpha_t \) is relatively higher in the sensitive periods of the process of growth. As the subscript \( t \) indicates, the velocity of growth can be time-variant. Consequently, the lag pattern in our height model may change over time.\(^1\)

Since the height series is observed from \( t = 1, \ldots, T \), the height–income relation of Eq. (3) cannot be estimated without making further assumptions: we only have \( T \) observations to estimate \( T \times (\tau + 1) \) parameters. Brinkman et al. (1988) make two additional assumptions:

(i) the curve of growth does not shift in time: \( \alpha_t(L) = \alpha(L) \);
(ii) the growth curve can be modelled by an appropriate polynomial lag for the matrix polynomial \( \alpha(L) \).

Under these assumptions Eq. (3) simplifies to the familiar model:

\[ H^*_t = \alpha(L)Y_t + \varepsilon_t. \tag{4} \]

The first assumption allows Brinkman et al. (1998) to assign weights to different ages that affect height: the Yearly Age- and Sex-Specific Increase in Stature (YASSIS), our \( \alpha(L) \). They estimate the YASSIS terms by a third degree polynomial lag. Coll (1998) simplifies their method by assigning a weight scheme with weights fixed for a number of years. By this he avoids the polynomial lag. Baten (2000) observes that the form of the second assumption does not generate statistically significant differences in outcomes.

### 4. The empirical method

Rather than estimating econometric models of height, we look for evidence of a change in the lag pattern by calculating correlation coefficients between height and some income and nutrition measures over different windows. To avoid spurious trend correlation, we first calculate deviations from trend, i.e. cycle components. We apply the Hodrick-Prescott (HP) filter to detrend our series (Hodrick and Prescott, 1997). This method has withstood the test of time and the fire of discussion remarkably well, and is likely to remain one of the standard methods for detrending (Ravn and Uhlig, 2002).

The detrending method assumes that an observed time series \( y_t \) in natural logarithms can be decomposed into a trend (or growth) component \( \theta_t \) and a cycle component \( c_t \):

\[ y_t = \theta_t + c_t. \tag{5} \]

\(^1\) Although this functional form is difficult enough to estimate, reality is even more complicated than this. In actuality, height velocity at time \( t \) is a function of the growth potential at that age, genetically determined, and \( Y_0, \ldots, Y_t \).
The HP filter removes a smooth trend $\theta_t$ from some given series $y_t$ by solving:

$$\min_{\theta_t} \sum_{i=1}^{T} [(y_i - \theta_i)^2 + \lambda((\theta_{i+1} - \theta_i) - (\theta_i - \theta_{i-1}))^2].$$

(6)

The residual $y_t - \theta_t$ is then commonly referred to as cycle component. The smoothing parameter $\lambda$, which penalizes the acceleration in the trend relative to the cycle component, depends on the frequency of observations. Ravn and Uhlig (2002) have demonstrated recently that $\lambda = 6.25$ is preferable for annual data and we use this value below.

Trend filters such as the HP filter are sensitive to the first few and the last few observations. Baxter and King (1999) recommend excluding at least three observations from either end of the sample when using the HP filter on annual data. We follow their advice and ignore the first three and the last three observations in the computation of correlation coefficients.

To search for evidence of a change in the lag pattern between height and income and nutrition measures, we calculate correlation coefficients between cycle components, i.e., deviations from trend, of height and (lagged) cycle components of various income and nutrition measures for rolling 31-year windows. For each window we calculate the correlation between the cycle components in height and a typical income or nutrition measure. Then we lag the series of the measure by 1 year and calculate the correlation coefficient again. We continue taking lags up to and including 21 years, the examination age plus one, capturing the year before birth.

In the correlation figures below we only show significant correlation coefficients. The HP filter may create spurious correlations between two uncorrelated I(1) series (Harvey and Jaeger, 1993). Therefore, standard confidence intervals for correlation coefficients which are based on the null hypothesis of uncorrelated white noise do not apply here. We calculated bootstrapped critical values for correlation coefficients between HP filtered series using 1000 replications. In each replication we generated two random series, cumulated these into random walks, calculated cycle components with the HP filter ($\lambda = 6.25$), and the correlation coefficient. The full series of 1000 correlation coefficients is then ordered which produces the critical value as the maximum of the values (in absolute value) that correspond to the 5 and 95% values of the distribution.

5. Data

5.1. Height

We use the median height of Dutch conscripts analysed by Drukker and Tassenaar (1997). Shifts in the year of measurement complicate the analysis of the height data. In 1861, this is the so-called end value problem. An example is a series experiencing a peak at the end of the sample. Then the HP-trend is different depending on whether information after the peak is included or not.

First we analyze the 1866–1896 period, then the 1867–1897 period, up to and including the 1880–1910 period. The bootstrap was introduced by Efron (1979) as a computer-based method for estimating the standard error of a distribution parameter. Our procedure follows Efron and Tibshirani (1993, Chapter 6).

The height series was compiled by Brinkman et al. (1988) on the basis of van Wieringen (1972), and revised by Mandemakers and van Zanden (1993). Median heights are calculated from a different changing number of frequency classes of observations.
the conscription laws were changed because of the increasing percentage of undersized conscripts. From 1863 on, the age of recruitment was raised from 19 to 20 years. Fig. 2 shows the median height series. For comparison a pre-1861 series of age-corrected mean heights estimated by Tassenaar (2000) is included. Differences in construction, such as the correction for the age of recruitment, sample coverage and overall quality, prohibit the use of this series in our computations below. Besides, the second part of the height series is more reliable than the first part, as can be seen from the difference in the fluctuations in the series.

The median stature of Dutch conscripts increased substantially and almost uniformly after the 1860 recruitments, even if the gains during the initial decade (1863–1870) were only a recovery to previous levels. Average height reached its nadir in 1857 (Tassenaar, 2000) after a period of decline starting in the 1840s. The phenomenon of decreasing heights in European countries in the early-industrial revolution era is known as the “early-industrial-growth paradox” (Komlos, 1998) In the 1860s height recovered somewhat in comparison to the late fifties, but stayed well below previous levels. The upward trend started with the cohorts

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Fig. 2. Average heights (cm) of Dutch conscripts at age 20 (with correction for age of measurement before 1862). Source: Drukker and Tassenaar (1997).

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6 As noted by Mandemakers and van Zanden (1993) conscripts were measured in the Spring before 1892, and in the Fall of the year thereafter, resulting in an increase in the average age of measurement from approximately 19(3/4) to 20(1/4) years. In our empirical analyses below we do not correct for this increase in measurement age. Some experimentation has shown that correction affects the quantitative outcomes, but does not change our main, qualitative conclusion.

7 Note that our income and nutrition measures derived from Smits et al. (2000) described below share this property.
Fig. 3. GDP per capita and real wages in the Netherlands; index numbers 1815 = 100 and 1913 = 100, respectively. Source: Smits et al. (2000).

5.2. Income measures

We distinguish two income measures: GDP per capita and real wages (Fig. 3). The estimates of Smits et al. (2000) are quite plausible and indicate that real GDP per capita had an almost constant growth rate from the end of the Napoleonic era until World War I. The development of real wages is slightly erratic in the first half of the 19th century, fluctuating around a more or less constant level. In the middle of the 19th century nominal wages started to rise after at least two centuries of stagnation. Real wages accelerated in the Netherlands after 1870 until the end of the century, interrupted only by recessions in 1876–1877 (the onset of the Agricultural Depression) and 1888–1890. Real wages fell in the first years of the 20th century partly due to an increase in the general price level, but rose sharply at the eve of World War I.

For a general overview of the economic history of the Netherlands in the 19th century see van Zanden and van Riel (2000).

The discontinuity around 1840 in the GDP per capita series is probably caused by improper accounting for the separation of Belgium. The separation took place de facto in 1830, but de jure in 1839 when the province of Limburg was split up.
5.3. Nutrition measures

Detailed information on nutrition in the Netherlands in the 19th century is unavailable.\textsuperscript{10} We use prices of two main ingredients of the 19th century diet: potatoes and bread (Fig. 4). Well into the 19th century the price of potatoes had a direct, inverse relationship to consumption. For the price of bread the situation was more complex, in as much as at least two varieties of bread were consumed, wheat bread and rye bread, the latter being an inferior good.\textsuperscript{11}

The potato price follows the general pattern of prices of agricultural goods. Until 1880 prices of agricultural goods generally became higher, thereafter they decreased.\textsuperscript{12} The potato price fell in the early 1880s and gradually became higher in the beginning of the 20th century. The price of bread had a downward tendency during most of the period considered.\textsuperscript{13}

\textsuperscript{10} The daily caloric intake and protein series of Knibbe (2001) are not long enough for our purposes.

\textsuperscript{11} Zeeman (1861) demonstrated the relationship between the price of rye and conscript height.

\textsuperscript{12} In the 1940s–1960s the potato price fluctuated heavily because of an almost endemic plant disease (phytophthora). This might also be a sign of the poorer quality of the price data in general and in the first half of the 19th century in particular.

\textsuperscript{13} The main reason for this downward tendency is technological progress which led to improvements in the milling process and a reduction in transport costs. In addition, institutional reforms like the abolishment of a levy on milling (in 1855) and huge inflows of grain especially from North America (from the early 1870s onwards) had a mitigating effect on the price of bread.
the end of the 19th century the bread price started to pick up, in line with the prices of all agricultural goods.

6. Results

Fig. 5 shows the cycle components in height, income and nutrition series. These are the residuals after applying the HP-filter on the natural logarithms of the series. We observe cyclical patterns, although the deviations from trend in case of the height series are smaller than the cycle components in the other series as can be seen from the scale on the vertical axes.

The next four figures show the correlations between cycle components of height and the income and nutrition measures, for moving 31-year windows with lags of up to 21 years. We show only the significant correlations (at the 10% level). In all figures the first window refers to the 1866–1896 period. Then the window is moved by 1 year, i.e., we look at 1867–1897, and repeat the analysis calculating the correlation coefficients between the cyclical components in heights and the (lagged) cyclical components in GDP per capita. We keep on moving the window until the final year of the window coincides with the final observation in our sample. The final window is the 1880–1910 period.

![Fig. 5. HP filtered cycle components.](image-url)
The correlation surfaces of Figs. 6–9 allow the following interpretation.\(^{14}\)

- The correlation between height and real wages (Fig. 7) stands out more clearly than the one between height and GDP per capita (Fig. 6). This outcome does not come as a surprise, because real wages have a more direct link to consumption and hence to the standard of living. The difference between our nutrition measures is less clear. The potato price seems more informative in terms of significant negative correlations with height than the bread price; the timing of the lags in the potato price has more direct links to growth-sensitive periods.

- If the lag pattern between height and its determinants is time-invariant, we expect the growth-sensitive periods just after birth and the adolescence growth spurt around the age of 17–18 years (Oppers, 1963) to show up in the graphs. This corresponds to hills (canyons) in the height–income (height–nutrition) figures at the lags of 18–21 and 2–3 years in all windows. Although both the real wages and the potato price (and to a lesser degree bread prices) are correlated with height at lags corresponding to the childhood growth spurt and the adolescence growth spurt in some windows, the correlations are not significant throughout the sample, i.e. in all windows. The hills (canyons) corresponding

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\(^{14}\) The correlations are between cycle components or deviations from trend of height and income and nutrition measures. We drop the cycle component prefix where it should not cause any confusion.
Fig. 7. Correlations between height and (lagged) real wage (10% level), the Netherlands 1863–1913.

- The adolescent growth spurt is more apparent in the correlation surfaces than the early childhood growth spurt. In addition, we do not find signs of a significant birth year effect, although pre-birth conditions show up in the first four windows of the height-GDP per capita correlations (Fig. 6).
- The significant correlation outcomes at a lag of 7 years between height and bread prices and potato prices, the 12-year lag for the bread price, and the lags of 12–13 years of the real wage series are hard to reconcile with the velocity curve of growth. Even the youth growth spurt (Oppers, 1963), cannot help us here, since that refers to youngsters at the age of 10–11 years, or lags of 9–10 years.

Note that correlation can also diminish over time because the population became wealthier and could handle shocks more easily.

This observation is in line with one of the conclusions of Baten (2000): the further away the time of measurement, the greater is the possibility to catch-up after a period of stunted growth caused by a deterioration in the standard of living. The period for adolescents to catch up after a period of stunted growth may well be too short.
A puzzling result is the occurrence of negative correlations at certain lags between height and GDP per capita (Fig. 6) and real wages (Fig. 7), and positive correlations at certain lags between height and the price series (Figs. 8 and 9). The canyon in the height-real wage graph (Fig. 7), and the mountain in the height-price of bread graph (Fig. 9) at the fourth lag are typical examples. The finding of favourable economic conditions 4 years before examination exerting a negative influence on height is implausible. A possible explanation might be as follows: the correlation coefficient between two series that are perfectly synchronised is equal to one. However, if we calculate correlations between one series and another series that is lagged up to the duration of the full cycle, the correlations fluctuate between 1 and −1. Another explanation runs as follows.\(^{17}\) Suppose that an economy is hit by a recession 2 years before a cohort of conscripts is measured. The mean height of this cohort will be negatively affected. Therefore, we would expect a positive correlation coefficient between height and the income measures at the second lag. If the economic conditions were beneficial around 4 years or half a business cycle earlier, in a less growth sensitive period, negative correlations outcomes could result at higher lags.

\(^{17}\) We thank a referee for this suggestion.
7. Conclusion

The aim of this paper is to explore the dynamic relationship between height and its determinants. We conclude that the correlations indicate a change in the lag patterns in the relationship between height and some income and nutrition measures, for the period under consideration.

To assess the significance of changing lags we calculate correlation coefficients between HP-detrended components in height and income and nutrition measures over moving windows. We find that the real wage is the most informative income measure and the price of potatoes the ‘best’ nutrition measure. The correlation between these two measures and height was strongest at lags corresponding to two well-known sensitive growth periods, early childhood and adolescence, the latter being the most pronounced.

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