Why did welfare improve during the Little Ice Age? Climate change, famines and nutritional status in early-modern France*

by *Ulf Christian Ewert***

Abstract: Aggregate changes in physical stature reflect the long-term development of a population's net nutritional status and they are determined by economic conditions and climate. In late 17th and early 18th centuries Europeans went through the coldest period of the last millenium. A series of annual French adult average heights enables to analyse the consequences of climate change for the human growth process in those times. The proposed model allows to estimate age-specific magnitudes of grain prices on the human growth process by controlling for climate variation. Estimates show that the volatility of grain prices can be forecasted very well with the given climate change, and that in turn the grain price level had a significant effect in shaping the terminal heigt of a birth cohort, especially during late youth and adolescence, that is at ages 13–18. In addition, it is also shown, that once the climate had started to become more moderate during the 18th century, the nutritional status of Frenchmen improved and famines had a less pronounced long-term effect on physical stature, presumably because grain markets became more integrated and thus enabled the French society to cope better with food shortages and subsistence crises than before.

Focus of the paper

Although showing already considerable economic progress, the French society of the late 17th and early 18th century can certainly be considered as being mainly rural in its character. At that time, French agriculture had to deal on a regular basis with the rather low temperature level and the overall poor climatic conditions that were typical for the so-called Little Ice Age. From around 1650 onwards, well into the second half of the 18th century, the agriculture then was repeatedly exposed to climate anomalies, these shocks causing a series of severe subsistence crises. Most prominent are the famines of 1650–52, 1661/62, 1693/94, 1709/10, 1740 and 1772. However, the impact of climate anomalies cannot only be observed in a short-term volatility of grain prices, it is also seen in the long-term development of the population's nutritional status. Subsistence crises seem to have left their marked footprints through abrupt falls in the average height for those birth cohorts that experienced starvation at a critical age (during adolescence, e.g.). To elaborate this general result concerning the complex interplay of climate, food shortages and the standard of living in more detail, the following questions will be discussed within the sections of this paper:

* Working paper prepared for *Rural History 2013: International Conference of the European Rural History Organisation (EURHO),* to be held at *University of Bern*, Switzerland, 19–22 August 2013. This text is an abridged and revised version of an earlier publication of the author (EWERT 2004).

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- What kind of impact of the Little Ice Age on the population's nutritional status is expected from a theoretical perspective?
- Is their also empirical evidence, that climate change and climate anomalies influenced the level of grain prices?
- How did the nutritional status of Frenchmen develop over time, and to what extent it was related to grain price fluctuations and winter temperatures?
- Can the assumed long-term effect of being exposed to famine really be seen in the development of physical stature, and how was this possibly related to population growth and an increasing integration of grain markets?

The Maunder Minimum and its potential repercussions on living standards

Between c. 1660 and c. 1760 Europe experienced the coldest period it has seen ever since the year 1000. Temperature in this so-called Little Ice Age was on average between 0.25 ºC and 0.5 ºC below the long-term mean. In addition, the amount of rainfall was much higher than normal[1]. Temperature had been at low levels before, for instance towards the end of the 16th century, but the persistence of adverse climatic conditions during late 17th and early 18th centuries was unprecedented. The extemely cold period streching from c. 1675 to c. 1715 is called Maunder Minimum. It is named in honour of E. Walter and Annie S. D. Maunder, English astronomers who were first at proving that the tremendous and persistent downturn of temperature in the late 17th century was due to a significant change in solar activity.[2] Since Europeans were faced about 2 to 3 generations with such an unfavourable climate, the welfare effects of these climatic conditions are worthwhile to be analysed.

It was already common knowledge to contemporary observers, that the standard of living in early modern Europe was to a large extent related to the level of grain prices. Well before the publication of Robert Malthus' »Essay on the Principle of Population«[3], this relationship was recognised in the discussion on political economy

[1] Cf. GLASER 2001, pp. 176–177, p. 181 (data for Central Europe). See also PFISTER 1999 and LE ROY LADURIE 1987. In the period 1666–1788, e.g., Swiss winter temperature, reconstructed with qualitative information from Basel, deviated by -0.241 ºC from the standard experienced during the first half of the 20th century (1901–1960). In the last decade of the 17th century this value dropped further down to -0.704 ºC. In this particular period even summer temperatures were significantly lower than normal (about -0.171 ºC, all deviations are calculated on the basis of data provided by Christian PFISTER). For France, annual average temperature in the late 17th and early 18th centuries is estimated to have been about 1 ºC below today's level. Cf. LACHIVER 1991.

[2] For the Maunder Minimum see e.g. FRENZEL, PFISTER, GLÄSER (eds.) 1994, pp. 151–171, GLASER 1996, pp. 56–88; GLASER 2001, pp. 175–176, GLASER, BECK 1997.

[3] Cf. MALTHUS 1798 (edition New York 1976).

in France during the 18th century[4]. Also empirical evidence was already published by that time. In 1766, the French scholar Louis Messance[5] published a study on the population of France (»Recherches sur la population de la France«), in which he showed with reference to annual data from Rouen for the period 1680–1699 that the relationship between grain prices, illness and mortality was negative indeed[6]. He arranged the data in such a way, that he was able to compare 10 years which he classified of having had moderate grain price and moderate numbers of deaths and ill persons with the 10 remaining years, in which grain price and the number of deaths and ill persons were high.[7]

Nevertheless, illness and mortality do reflect only short-term consequences of a worsening economic situation for the standard of living, although these consequences usually have been very severe. In addition, the long-term effect of adverse economic and environmental conditions on the human growth process was prevalent, although presumably not that visible for everyone as were the short-term effects of illness and mortality. Nevertheless, long-term consequences can be traced by studying time trends in human growth[8]. Even if young people did not die or did not become seriously ill during a period of food shortage and elevated grain price, such economic conditions must have influenced their individual growth path with the consequence that they did not become as tall as they could have grown in more favourable economic circumstances[9]. Thus, the impact of bad economic and nutritional conditions experienced during the growth process is stored permanently in physical stature and shows up as stuntedness. On a macro-level, unfavourable economic and environmental conditions are visible through a reduced average height of a birth cohort.

There is strong empirical evidence, that a population's biological standard of living, measured in terms of average height, is generally affected by the climate conditions the population lives in. STECKEL compares the course of temperature during the

[4] Cf. GÖMMEL, KLUMP 1994.

[5] On Louis Messance see BRIAN, THÉRÉ 1998, pp. 45–92.

[6] *Les années où le bled a été le plus cher ont été en même temps celles où la mortalité a été la plus grande et les maladies plus communes, et celles au contraire où le bled a été à meilleur marché, ont été les plus saines et les moines mortelles*. MESSANCE 1766, pp. 280–292 [printed in GUILLAUME, POUSSOU (eds.) 1970, pp. 163–165], p 165.

[7] Cf. MESSANCE 1766, pp. 280–292 [printed in GUILLAUME, POUSSOU (eds.) 1970, pp. 163–165], p. 163. Regressing the number of deaths and the number of ill persons on wheat price and the squared wheat price shows that variations of these measures of the standard of living are explained by ca. 82.5% (deaths) and by ca. 68.6% (ill persons) by varying wheat prices.

[8] Cf. TANNER 1994, pp. 1–6; CUFF 1995, pp. 1–15; STECKEL 1995, pp. 1903–1940; WOITEK 2003, pp. 243–257.

[9] Cf. KOMLOS, HAU, BOURGUINAT 2003, pp. 159–189.

last millenium (c. 1000–2000) with the development of human height in Northern Europe. His assessment of medieval skeleton remains indicates clearly that people during the very warm period in the Middle Ages (c. 1150–1300) were on average as tall as Europeans were at the beginning of the 20th century[10]. In turn, people were extremely short at the end of the 17th century, when annual average temperature in Western and Central Europe reached its minimum of the millenium. This is herein shown with the height records of soldiers serving in the French army starting with birth cohorts of 1666[11]. The rapid increase of their average height at the turn of the 18th century coincides with the end of the Maunder Minimum.[12] BATEN shows that heights decreased in Southern Germany in the second half of the 18th century corresponding to the then temporary downturn of climate[13]. And also the marked decrease of Saxon average height in early 19th century can partly be attributed to an again worsening climate, as is shown by several studies of EWERT.[14]

That climatic conditions affected a population's biological standard of living seems like a reasonable hypothesis. Because average height reflects the net nutrional status of a population, changes in average height over time are to a large extent driven by changes in the availability and the composition of nutrients. Since in pre-industrial agricultural societies harvests mainly were determined by climatic conditions[15], the net nutritional status was indirectly influenced by climate through abundance or scarcity of grain and other foodstuffs. The production of proteins (milk and meat) was also affected by climate because the quality of pastures relied on how long they were covered by snow during winter and on when the grass began to grow in the spring[16]. France in the late 17th and early 18th centuries was certainly not an exception to this rule.

In pre-industrial societies climate affected average height not only indirectly via the availaibility of calories and proteins. Climate had direct effects on height as well.

[10] STECKEL 2004, pp. 211–229.

[11] KOMLOS, HAU, BOURGUINAT 2003.

[12] See KOMLOS, EWERT 2002.

[13] From birth cohorts 1750 to 1770, the average height of Bavarian adult males decreased from a level of over 168 cm to about 165 cm. Cf. BATEN 2001, p. 34, Figure 8.

[14] See EWERT 2006 and EWERT 2007. Decrease in height was tremendous, as average height of Saxon adult males went down from about 168 cm (birth cohorts 1770 to 1780) to less than 163 cm (birth cohorts 1835 to 1850). Cf. EWERT 2006, pp. 56–63.

[15] Winter temperature, snow coverage and the springtime level of temperature determine the length of the grain's growth period and the intensity of growth, whereas the quality of the grain harvested is determined by the degree of humidity during the summer and early autumn. Cf. PFISTER 1988a, pp. 34–35.

[16] Cf. PFISTER 1988b, pp. 38–39 and BATEN 2001, p. 30.

Winter temperature seemed to play a fundamental role for the explanation of inter-cohort height differentials. Extremely cold winters obviously were a severe hindrence to human growth in pre-industrial societies, because given the poor clothing of most people and the poor housing conditions the majority of them lived in, it forced a child's organism to use the calorific value of food intake for maintenance of the basal metabolic rate instead of using it for growth[17]. Therefore, more favourable winter weather conditions fostered human growth by suppressing inhibiting factors.

Modelling the effects of climate for human growth

With annual data on human height, indicators of climate and grain prices available, age-specific direct and indirect effects of climate on average height can be calculated. In order to estimate such age-specific effects of climate, a simplified causal model is assumed[18]. In this model climate is a latent variable, measured in various dimensions: average temperature (in England)[19], indices of summer temperature and the quantum of rainfall during autumn (in Switzerland)[20] and treering growth (in the region of Burgundy)[21] are used to forecast the level of grain prices (see **Figure 1**). Winter temperature (in Switzerland) is then used as the only proxy for weather condition that could have affected height directly.

[17] Cf. KOMLOS, HAU, BOURGUINAT 2003 and KOMLOS, EWERT 2002.

[18] Annual market prices for wheat and oats from the city of Douai in Northern France are used as indicator for the development of prices in France. See MESTAYER 1963, pp. 168–173, for the publication of series. Wheat and oats prices for Douai have been aggregated to a single price index which represents the price (in *livres tournois*) of a fixed quantity of grain, 100 liters of wheat and 100 liters of oats each. Up to 1667 the city of Douai belonged to the Spanish Low Countries. Following the death of the Spanish King Philipp IV, Louis XIV claimed the heritage and subsequently conquered the southern parts of Flanders. With the Treaty of Aachen (1668) Douai then became officially part of the French crown. The grain market of Douai together with the market of Valenciennes had regional importance since the Middle Ages, because grain was traded to the Low countries from there. Since in the 17th and 18th centuries local grain markets were integrated to a large degree, series of grain prices from various locations show the same cyclical pattern. The Douai grain price series is highly correlated with the Paris grain price series published by BAULANT 1968, pp. 537–540 (for 1666–1788 the correlation coefficient r is *0.617*) and with the series of grain prices in the city of Beauvais ($r = 0.671$), published by GOUBERT 1960.

[19] Cf. MANLEY 1974. For France, Paris annual climate data is available for only part of the period under consideration, drawn from the recordings made by Louis Morin, who measured temperatures between 1675 and 1713. See LEGRAND, LEGOFF 1992 and PFISTER, BAREISS 1994, pp. 151–171. For the period of 1676–1712 the average temperature in Paris is correlated to the average temperature in England with $r = 0.636$. The winter temperature in Paris (average temperatures in December, January and February) is correlated to the Swiss winter temperatures with $r = 0.799$.

[20] The long-term average based on measurements in the period 1901–1960 is indicated with 0. Deviations from this standard are scaled up to +3 (very hot summer, very wet fall) and down to –3 (very cold summer, very dry fall). For the reference period both index values and temperatures measured in ºC are known and index values for past centuries can be converted into deviations (in ºC) from the long-term temperature mean. Cf. PFISTER 1988a, p. 31. For regression either index values or converted temperature deviations can be used, because the latter simply are linear transformations.

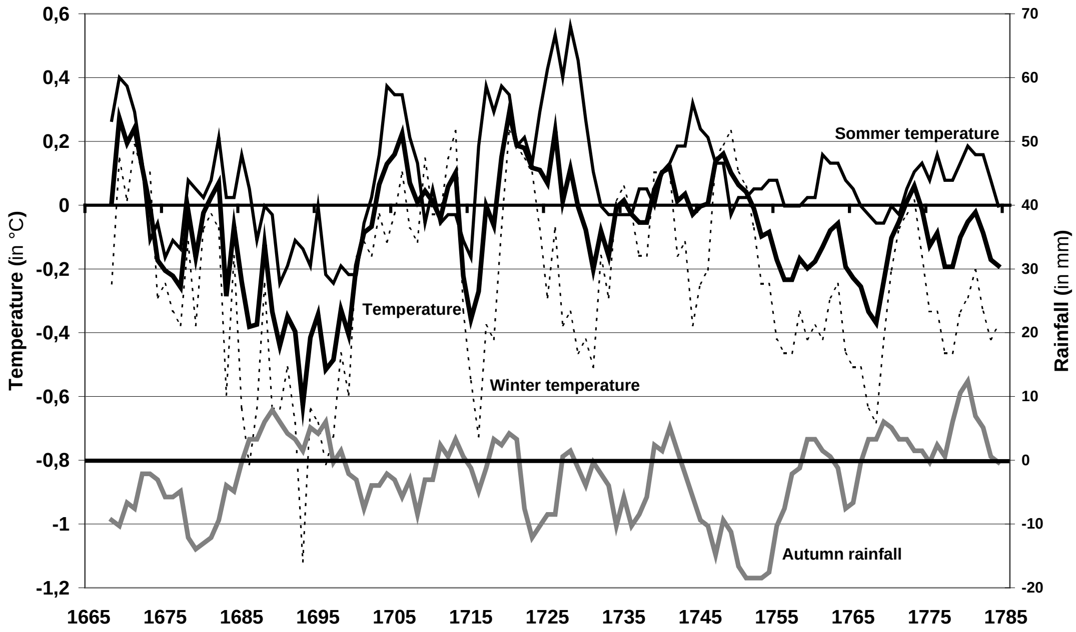


Figure 1. *Five-year moving averages of Swiss climate indicators from their 20th century normal level, of the period of 1901–1960.*
Source: Author's own calculations on the basis of data published by PFISTER 1988a.

The specification of the model has to be restricted to the interplay between indicators of climate, grain prices and cohort-specific average height, because these variables can be measured on an annual basis. In order to control for the effect of population growth, decennial population growth rates are split into annual growth rates assuming constant growth during a particular decade.[22] Feed-back effects between the growth of population and the economy are excluded due to a small correlation coefficient[23], as is the causal influence of climate on population growth[24]. In relying on theoretical considerations and estimation results from a more complex model published by EWERT[25], one can assume that *ceteris paribus* a more moderate and warmer climate fostered the growth of physical stature of humans, whereas a high level of

[21] Cf. DE VRIES 2000 [*www.unc.edu/depts/anthro/ french/projects/ climate/ data_hist...*]. See also MURRAY 2001 [*www.unc.edu/ depts/anthro/ french/projects/climate/introduction...*].

[22] Population growth rates for France in the 17th and 18th centuries are calculated from population figures published by DUPÂQUIER 1979.

[23] The correlation between log grain price and population growth rate is $r = -0.102$. If climate effects are removed from the log grain price (by using the residuals of a regression of log price on indicators of climate), this bivariate correlation is even smaller ($r = -0.042$).

[24] For several indicators of climate relatively small bivariate correlations with the growth rate of population were found: log average temperature in England ($r = 0.281$); log index of winter temperature ($r = 0.029$); log index of summer temperature $r = 0.111$); log index of autumn rainfall ($r = 0.013$). Thus, climate seems to be virtually uncorrelated with population growth.

[25] See EWERT 2004, pp. 33–38.

prices for grain reduced average height. Furthermore, a moderate climate should reduce the level of grain prices. Since a moderate climate reduced the propensity of harvest failures and commonly improved the quality of harvest, grain prices were moderate, too, which in turn also allowed people to grow taller. Thus, it can be assumed that a birth cohort that experienced a moderate climate during youth and adolescence should have shown a higher average height than a birth cohort which grew up during more extreme climate conditions.

The twofold impact of climate on physical stature is modelled in two equations: equation **[1]** relates average height of a birth cohort born in year t to grain prices p and winter temperatures c^w experienced by this birth cohort during the growth process, which can be written as an integral over the years between the year of birth and the year in which human growth usually is completed (for convenience, the age of 23 herein is taken as age where on average people stopped to grow taller)[26]:

$$[1] \qquad h_t = \int_{a=t}^{a=t+23} f\,(p_a ; c_a^w)\, da$$

Equation [2] models the level of grain price in year t as a function of levels of the J climate indicators (c_{jt}), these indicators being English average temperature, indices of Swiss winter and summer temperature, Swiss autumn rainfall and treering growth in the region of Burgundy:

$$[2] \qquad p_t = \alpha_p \prod_{j=1}^{J} c_{jt}^{\kappa_j} e^{v_t}$$

However, it is not only a question whether grain prices and temperatures were able to influence physical stature or not, one also has to think about the time structure of these influences. Obviously, the total effect is distributed over the course of human growth, and by assumption, these age-specific effects accumulate in the process. Average growth velocities are known from the growth curve which is often referred to as curve of *Yearly Age- and Sex-specific Increase in Stature* (YASSIS). Environmental and economic conditions presumably did not affect the growth of physical stature with the same magnitude at all ages during youth and adolescence. By applying a polynomial distributed lags regression to equation [1][27], the specification of the model allows to estimate age-specific effects of climate on average height.

[26] For this assumption see KOMLOS 1989, p. 29, and KOMLOS, HAU, BOURGUINAT 2003.

[27] This approach has been used for the analysis of lagged influences of GDP per capita on the prevalence of stunting in developing countries by BRINKMAN, DRUKKER, SLOT 1988, pp. 227–264 and BRINKMAN, DRUKKER, SLOT 1997.

Effects of climate on the grain price level

First of all, the effects of climate on the grain price level are considered. The log transformation of equation [2] is estimated on the basis of 119 annual observations (1668–1786) with *Ordinary Least Squares* (OLS) assuming that v_t is distributed with zero mean and a constant variance σ_v^2. Three different specifications were tested: a multiplicative model including all climate indicators as regressor variables (*Model Ia*), a multiplicative model leaving aside winter temperature and lagged autumn rainfall (*Model Ib*)[28] and, finally, a multiplicative model with the same set of regressor variabels as in *Model Ib*, but assuming an u-shaped relationship between summer temperatures and grain prices instead of a linear one (*Model Ic*)[29]. As can seen from the bivariate correlations depicted in **Table 1**, climate indicators are virtually uncorrelated.

	Average temperature	Autumn rainfall	Summer temperature	Winter Temperature
Autumn rainfall	-0.127			
Summer temperature	0.302	-0.195		
Winter temperature	0.346	-0.129	0.163	
Treering growth	0.106	-0.128	-0.043	0.190

Table 1. *Bivariate correlations (Pearson's r) between log values of climate indicators.*

Regression results are shown in **Table 2**. In general, as expected, a warmer and dryer climate reduced the price of grain, because harvest conditions were better[30]. The dryer the period of harvest, the lower were grain prices. In contrast to physiological

[28] For these two multiplicative models all Swiss climate indices were transformed by adding +4 to each observation, so that for every index the worst situation is represented by +1 and the best by +7. The underlying assumption with these models is, that the effect of climate was uni-directional (e.g., higher temperatures reduced grain prices and vice versa), but not necessarily linear.

[29] The idea with this specification is to estimate the effect of deviations from the long-term average summer temperature, because it makes sense to assume, that extremely hot summers and extremely cold summers either had negative consequences for harvests and therefore increased the grain price. For that purpose the index of summer temperature was transformed by adding +4 to the absolute value of each observation. Hence, the normal situation is represented by +4 and the most outstanding situations are indicated with +7 (either extremely hot or extremely cold summer).

[30] There is one exception to this rule, because parameter estimations indicate that high summer temperatures increased the grain price level, although this impact was not significant. This possibly points to the fact that an optimal temperature level during summer was needed which is not entirely modelled in *Model Ia* and *Model Ib* where a uni-directional relationship between grain prices and summer temperatures is assumed. The effect of summer temperatures increases, when negative and positive deviations from the long-term mean are treated equally (*Model Ic*), indicating that either a too cold summer or a too hot summer decreased quantity and quality of harvested grain and therefore increased the grain price.

considerations[31], the degree of humidity during fall one year before has had no influence on the price level at all. Also, when controlling for other climate indicators, the effect of the winter temperature index on grain price was statistically not significant. Since the growth of trees reflects better than other climate indicators the optimal combination of different dimensions of climate, namely the match or mismatch of temperature level and the degree of humidity, it is not a surprising finding, that in years with a considerable growth of treerings grain price was low and vice versa. This effect was stretched for several years into the future, because trees very often react to favourable climatic conditions in a particular year also with growth in subsequent years.

Dependent variable: log grain price	**Model Ia** (OLS-AR1)	**Model Ib** (OLS-AR1)	**Model Ic** (OLS-AR1)
CONSTANT	6.50495***	6.54229***	5.46672***
log average temperature	-1.29451***	-1.34698***	-1.07008***
log average temperature {*t-1*}	-1.01329**	-0.99934**	-0.88664**
log autumn rainfall	0.17637*	0.18447**	0.14931*
log autumn rainfall {*t-1*}	-0.00944	———	———
log summer temperature	0.13196	0.12868	0.33091
log winter temperature	0.03170	———	———
log treering growth {*t+2*}	-0.37512**	-0.38112**	-0.46823***
log treering growth {*t+1*}	-0.32664*	-0.32089*	-0.29161*
log treering growth	-0.40941**	-0.42950**	-0.49545***
Coefficient of autocorrelation	0.68537***	0.68546***	0.67963***
Years *t* = 1668-1786 (*n* = 119)	$R^2 = 0.572$ $R^2_{adj.} = 0.532$ DW = 1.802 df = 108	$R^2 = 0.571$ $R^2_{adj.} = 0.539$ DW = 1.800 df = 110	$R^2 = 0.574$ $R^2_{adj.} = 0.543$ DW = 1.858 df = 110

Table 2. *OLS parameter estimates for effects of log climate on log grain prices. The effects are reported as percentage change in grain price due to an one-percent change in the regressor variable. Significance levels for two-sided t-tests are denoted with *(p≤0.1), **(p≤0.05) and ***(p≤0.01).*

Effects of the grain price level and winter tempratures on physical stature

With a series of average height of French male adults born between 1666 and 1763, established by KOMLOS, HAU and BOURGUINAT from French military records[32], it

[31] A too high degree of rainfall during autumn is supposed to reduce not only the quality of the actually harvested grain, but also to wash out minerals and nutrients from soil with the effect, that the following year's growth of grain is hampered as well. Cf. BATEN 2001, p. 31. In addition to that, excess humidity in autumn hindered and delayed the sowing of springtime crops. Cf. PFISTER 1988a, p. 35.

[32] The information on height has been extracted from military records surviving in the French Military Archives, Château de Vincennes, Paris. For a detailed description of these data see KOMLOS, HAU, BOURGUINAT 2003.

then becomes also possible to assess the effects that changing economic as well as climatic conditions had on the development of physical stature over time. Since the French height series is the earliest of such series available, it becomes possible with these particular data to obtain insights into the state of the biological standard of living at the turn from the 17th to the 18th century. And this period is of particular interest, because it marks the end of the Maunder Minimum and is characterised by a beginning secular improvement of climate, especially of temperature during the first decades of the 18th century[33]. As can be seen from the graph in **Figure 2**, average height of Frenchmen increased tremendously from late 17th century until the second half of the 18th century.

To model a time structure of the effects on average height, the height data on birth cohorts is shifted forward on the time axis such that $h_{t'}$ represents the average height of a birth cohort born in year t at year $t' = (t + 23)$, the year when growth of physical stature was completed for this particular birth cohort. The representation of cumulative economic and climatic effects as an integral now can be rewritten as a function with a finite lag structure:

$$[3] \qquad h_{t'} = \alpha_{ht'} \prod_{i=0}^{23} p_{t'-i}^{\beta_{pi}} \prod_{i=0}^{23} c^{w\beta_{ci}}_{t'-i} e^{u_t}$$

The multiplicative functional form was chosen, because height is unlikely to be related linearly to price level and winter temperature. Natural lower and upper boundaries exist for height, that is people are not going to grow to infinity with temperature rising and they will not shrink to zero even if increases of grain prices are tremendous. The parameters β_{pi} and β_{ci} are then elasticities, which measure the percentage change of average height due to an one-percent change of grain price and winter temperature in year (t'-i) – which is in fact age (t+i). This yields relative magnitudes of age-specific impacts that easily can be compared with each other.

For the time-dependent constant two alternative specifications are used: the first specification [*a*] leaves the development of heights over time that cannot be attributed to the level of grain price and winter temperature unspecified. Here only cohort-specific additional effects d_j for 10-year birth cohorts are included, the birth years of

[33] This tremendous rise of temperature was reversed temporarily in the second half of the 18th century when European climate started to become colder again for the time of about two decades. Cf. GLASER 2001, p. 181; GLASER, BEYER, BECK 1999, pp. 23–46.

1666–1679 being the reference category[34]. The second specification [*b*] incorporates a linear time trend and controls for effects of average population growth $\check{n}$ experienced during the growth process and the population growth rate n_t in the year of birth. In this model the hypothesis that population growth was the key parameter to influence the standard of living in a Malthusian demographic regime can be tested. Depending on the sign of the parameter estimates a conclusion can be drawn on whether the Malthusian mechanism of negative consequences of population growth has been overcome or still not.

Assuming that u_t is distributed with zero mean and a constant variance σ_u^2, the log transformation of equation [3] can be estimated using OLS, yielding two series of age-specific effects of grain price and winter temperature on height for ages 0–23. In order to obtain a smoothly behaving series of lagged coefficients for economic and climate effects instead of effects that are allowed to change signs erratically between ages, restrictions are imposed on the estimation of lagged regression coefficients such that the series of coefficients can be described in terms of a s-th-degree polynomial[35]. Four different specifications of the model were tested: *Model II* without any effects of winter temperature and grain price on average height; *Model III* with freely varying parameters; *Model IV* with a second-degree polynomial and *Model V* with a third-degree polynomial specification for both independent variables. All four models were alternatively estimated by assuming the cohort effects specification [a] and the population growth specification [b][36].

At first, the level of average height of French adult men in the 17$^{\text{th}}$ and 18$^{\text{th}}$ centuries was influenced by changing levels of weather conditions during winter and by a

[34] The last 14 birth cohorts in the sample, the birth years of 1750–1763, were also put together into one category.

[35] See JOHNSTON [3]1984, pp. 352–358, on the econometrics of polynomial distributed lags model (Almon lag model). Whether these restrictions on the estimated regression coefficients are reasonable or not can be tested by comparing the performance of such a model to that of the free parameter estimation with a F-test.

[36] Because the average height of birth cohorts is analysed instead of individual height records and since the mean for each birth cohort was estimated using a different number of observations, residuals of the OLS-regression either of the free parameter estimation or the polynomial distributed lags model tend to be heteroskedastic. The estimated error terms tend to decrease with the number of observations per birth cohort increasing. This is the case, because average height of a birth cohort can be estimated more precisely with an increase in the number of observations per birth cohort at hand. Because of that, all specifications are estimated with *Weighted Least Squares* (WLS), the time series entries each being weighted with the square root of the number of observations for the corresponding birth cohort. This yields not only unbiased but also consistent estimates of the effects under consideration. With the exemption of the second-degree polynomial distributed lags model, regressions of log squared residuals on log observations yield statistically negative coefficients for the log observation variable. Thus, the hypothesis of heteroskedasticity cannot be rejected.

changing grain price during the period of human growth[37]. Forecasted values of average height are highly correlated with the original data (see **Figure 2**). Furthermore, compared to the free parameter estimation of temperature and price effects on height the polynomial distributed lags specifications fit the data sufficiently well[38]. The estimation results are shown in **Table 3**.

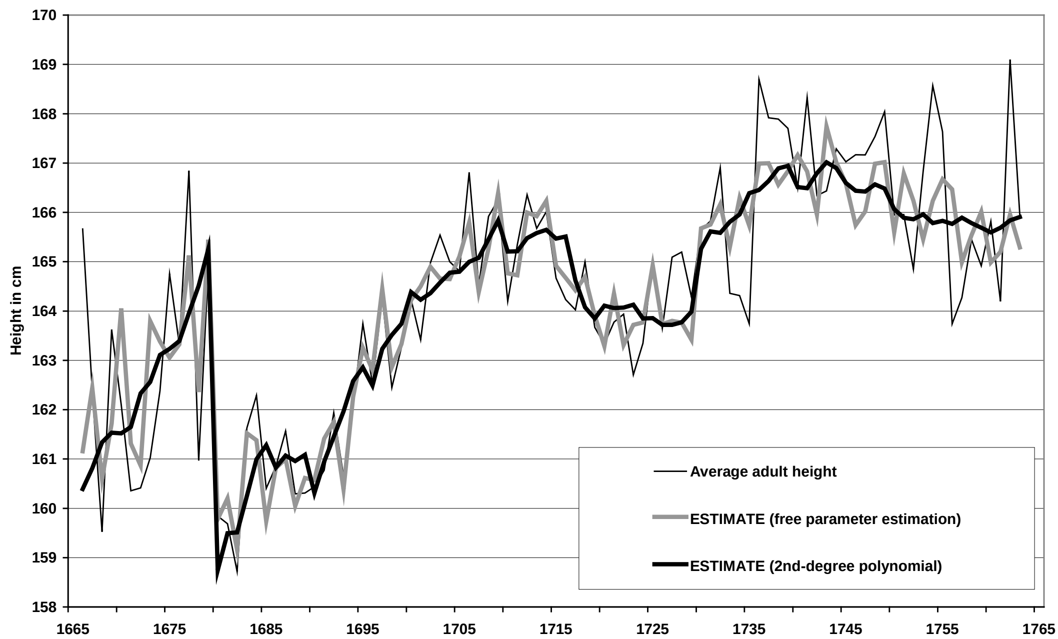


Figure 2. *Development of average heights for birth cohorts 1666–1763 and heights forecasted on the basis of a model without any restrictions on effects of lagged grain prices and winter temperatures (Model IIIb) and with a second-degree polynomial distributed lags model (Model IVb). Estimated values are correlated to original heights with r = 0.890 (free parameter estimation) and r = 0.843 (second-degree polynomial of lagged coefficients).*

[37] Measured in terms of variance of the log average height series explained, the regression of average height on lagged winter temperatures and grain prices improves the fit considerably ($R^2 = 0.580$ with the population growth specification of *Model IIb* vs. $R^2 = 0.794$ with the free parameter estimation of *Model IIIb*). The F-value of 1.725 with 48 (numerator) and 44 (denumerator) degrees of freedom is significant on the 5-% level. This result holds although not being significant also with the cohort effects specification. In this specification far more of the variance is explained even when temperature and grain price effects are not included in the model, because each cohort experienced a different environment which presumably is due to different conditions of climate and different grain prices.

[38] The polynomial distributed lags models have a higher adjusted R^2_{adj}. See **Table 3**.

Dependent variable: Height [ln($h_{t'}$)]	**Model IIa** (WLS)	**Modell IIb** (WLS)	**Model IIIa** (WLS)	**Model IIIb** (WLS)
CONSTANT (α_{h0})	7.39486***	7.35253***	7.36645***	7.31997***
Birth cohort 1680–89	-0.01345***	————	0.00385	————
Birth cohort 1690–99	-0.00369	————	-0.01298	————
Birth cohort 1700–09	0.01481***	————	0.01915	————
Birth cohort 1710–19	0.01407***	————	0.00593	————
Birth cohort 1720–29	0.00657*	————	0.00279	————
Birth cohort 1730–39	0.01989***	————	0.01144	————
Birth cohort 1740–49	0.02660***	————	0.01094	————
Birth cohort 1750–63	0.01710***	————	0.01246	————
Population growth in the year of birth	————	-0.11858***	————	-0.19717***
Population growth in the year of birth (growth rate > 0 and < 0.2%)	————	0.18350***	————	0.27323***
Population growth in the year of birth (growth rate > 0.2%)	————	0.13330***	————	0.20421***
Average population growth	————	0.06489***	————	0.08101***
Time trend	————	0.00038***	————	0.00055***
Residual sum of squares (weighted)	0.75563	1.0153	0.34076	0.35227
Birth cohorts t = 1666–1763 Years t' = 1689–1786 (n = 98)	R^2 = 0.684 $R^2_{adj.}$ = 0.656 DW = 1.704 df = 89	R^2 = 0.580 $R^2_{adj.}$ = 0.557 DW = 1.200 df = 92	R^2 = 0.793 $R^2_{adj.}$ = 0.511 DW = 1.716 df = 41	R^2 = 0.794 $R^2_{adj.}$ = 0.547 DW = 1.673 df = 44

Dependent variable: Height [ln($h_{t'}$)]	**Model IVa** (WLS)	**Model IVb** (WLS)	**Model Va** (WLS)	**Modell Vb** (WLS)
CONSTANT (α_{h0})	7.43918***	7.36423***	7.38692***	7.36566***
Birth cohort 1680–89	-0.01875***	————	-0.01002	————
Birth cohort 1690–99	-0.01134	————	-0.01276	————
Birth cohort 1700–09	0.00507	————	0.00748	————
Birth cohort 1710–19	0.00085	————	0.00042	————
Birth cohort 1720–29	-0.00128	————	-0.00173	————
Birth cohort 1730–39	0.01394	————	0.01058	————
Birth cohort 1740–49	0.02819***	————	0.01949**	————
Birth cohort 1750–63	0.03354***	————	0.02452**	————
Population growth in the year of birth	————	-0.18407***	————	-0.14762***
Population growth in the year of birth (growth rate > 0 and < 0.2%)	————	0.25125***	————	0.22443***
Population growth in the year of birth (growth rate > 0.2%)	————	0.19166***	————	0.15996***
Average population growth	————	0.07537***	————	0.06585***
Time trend	————	0.00062***	————	0.00053***
Residual sum of squares (weighted)	0.65305	0.57619	0.58905	0.54658
Birth cohorts t = 1666–1763 Years t' = 1689–1786 (n = 98)	R^2 = 0.686 $R^2_{adj.}$ = 0.633 DW = 1.745 df = 83	R^2 = 0.712 $R^2_{adj.}$ = 0.675 DW = 1.743 df = 86	R^2 = 0.718 $R^2_{adj.}$ = 0.662 DW = 1.867 df = 81	R^2 = 0.720 $R^2_{adj.}$ = 0.677 DW = 1.763 df = 84

Table 3. *WLS parameter estimates for regressions of log heights. Significance levels for two-sided t-tests are denoted with *(p≤0.1), **(p≤0.05) and ***(p≤0.01).*

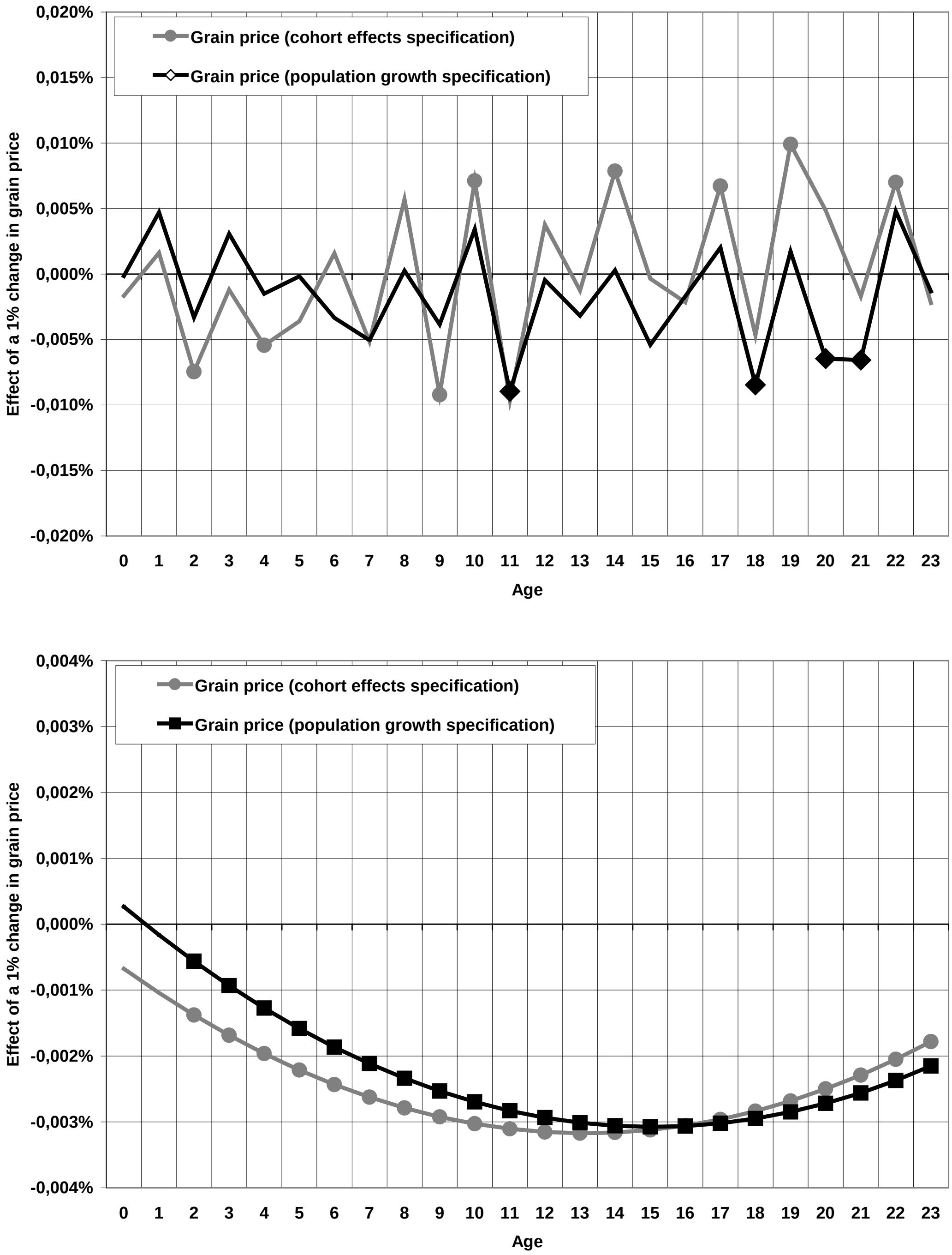


Figure 3. *Effect of grainprice on height for french birth cohorts 1666–1763 (elasticities). The lagged coefficients are estimated without restrictions and freely varying parameters (top) and with a third-degree polynomial (below). Both models are controlling for either cohort effects or population growth. Dots indicate effects that are significant at least at the 10%-level in a one-sided t-test.*

Analysis herein is primarily focussed on the time structure of grain price effects on average height which is depicted in **Figure 3**.[39] As expected, the unrestricted estimation of effects yields mixed results with signs changing between ages (**Figure 3**, top

[39] For results regarding the time structure of winter temperature effects on average height see EWERT 2004, pp. 46–47.

panel). Moreover, many of the lagged regression coefficients are not statistically significant. Thus, imposing a functional form seems to be justified by the properties of the data. For the grain price level a second-degree polynomial is thus a quite sufficient representation of the effects' time structure (**Figure 3**, bottom panel)[40]. Grain prices were especially important at the ages of 13–18. The more expensive grain was, the shorter a cohort grew on average.

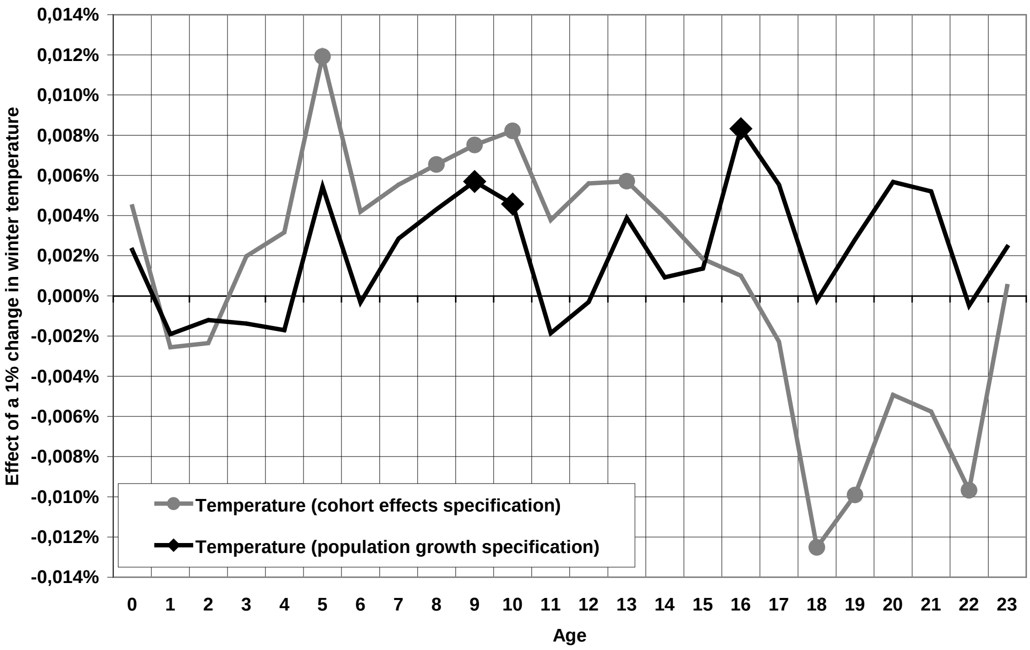
In **Figure 4** the estimated time structure of winter temperature effects on average height is shown. It is only for winter temperatures plausible to assume a direct impact on average height, since the experience of very cold winters during the growth period must have hampered the growth of physical stature, because calories needed to grow were used to maintain fundamental bodily functions. Following the estimations of the polynomial distributed lags model, more moderate winter temperatures imply a higher average height, with the peak of influence also in late youth and during adolescence (at ages 13–18), when an one-percent increase in the temperature index caused about 0.0025 percent increase in average height (**Figure 4**, bottom panel). Up to age 3 low winter temperatures increased average height, which can be explained by natural selection. Very young children, who had a very weak constitution (and possibly because of this weak constitution would have grown less), were not very likely to survive the demanding environmental conditions. Therefore, the average height of a particular cohort tended to be greater without these children who died during early childhood.

Besides the age-specific direct effects of winter temperature on average height that are estimated in the height regression [3], indirect effects of climate can be derived from the two equations. These compositional effects are calculated by multiplying the effects of climate indicators (average temperature, summer temperature, autumn rainfall and treering growth) for the level of grain price with the age-specific effects of grain price on average height. With this method indirect elasticities of height with respect to variation in climatic conditions are obtained. Values for grain

[40] The F-test of *Model IVb* against *Model Vb* reveals that the additional restrictions that are put onto the data by using a second-degree polynomial instead of a third-degree polynomial do not lead to significant differences (F-value of 2.275 with 2 (numerator) and 84 (denumerator) degrees of freedom, $p = 0.109$). Especially for grain price, the change in the overall sketch of age-specific effects when imposing the more flexible third-degree polynomial on the data is not worth mentioning, but with a second-degree polynomial more statistically significant age-specific effects are obtained. In contrast, the sketch of age-specific winter temperatures effects on height differs to some extent between the two polynomial lags specifications. Therefore, no terminal conclusion, where exactly the peak of influence of winter temperature lies can be drawn.

price effects are taken from the estimation of the second-degree polynomial distributed lags model that includes population growth parameters (*Model IVb*). The decomposition relies on the forecast of the grain price level with the multiplicative model including uni-directional influences of all climate indicators on grain prices (*Model Ib*)[41]. The sum of all indirect effects peaks around ages 13–18, because in these ages the grain price effects were most powerful in shaping final average height. Of all climate indicators other than winter temperature English average temperature and Burgundian treering growth had the most pronounced impact on average height, whereas the effect of summer temperature and autumn rainfall were of minor importance in comparison. Thus, the specific conditions just before and during harvest time seemingly were not as important for determining the biological standard of living as one may tend to think. More interestingly, in relation to the overall effect of climate, given as sum of age-specific effects of winter temperature and age-specific indirect effects of other indicators of climate, the winter temperature effects count for only about ¼ of the overall impact on height. For the ages where overall influence of climate peaked, this overall impact was in the order of 0.012–0.014 percent increase in average height caused by a one-percent change of each of the indicators of climate under consideration. Thus, the various climate dimensions generally were able to shape the biological standard of living in Ancien Régime France. Although at first glance a value of between 0.012–0.014 percent may suggest a rather inelastic reaction of average height to changes in climate, given the tremendous improvement of climate that got under way during the first half of the 18th century, even these small annual reactions summed up to some additional height over the course of the human growth process. Following the decomposition into direct and indirect impacts of winter temperature the overall effect sums up to 0.191 percent during the 23 years of growth. As a consequence, a cohort that would had experienced a constant improvement of climate in the order of only one percent in each of the growth years, would have been on average about 0.31 cms taller than a cohort 161 cms tall that had lived in unchanging climatic conditions.

[41] Alternatively, the overall effect of climate on height was also decomposed on the basis of grain price forecasted with the multiplicative model including the U-shaped relationship between grain prices and summer temperatures (*Model Ic*). Patterns that are obtained from the two different calculations are very similar to each other, the only difference being, that due to the larger effect of extreme summer temperature phenomena in *Model Ic* the relative importance of other indicators of climate is slightly reduced and also the total effect of climate is smaller than in decomposition described above.



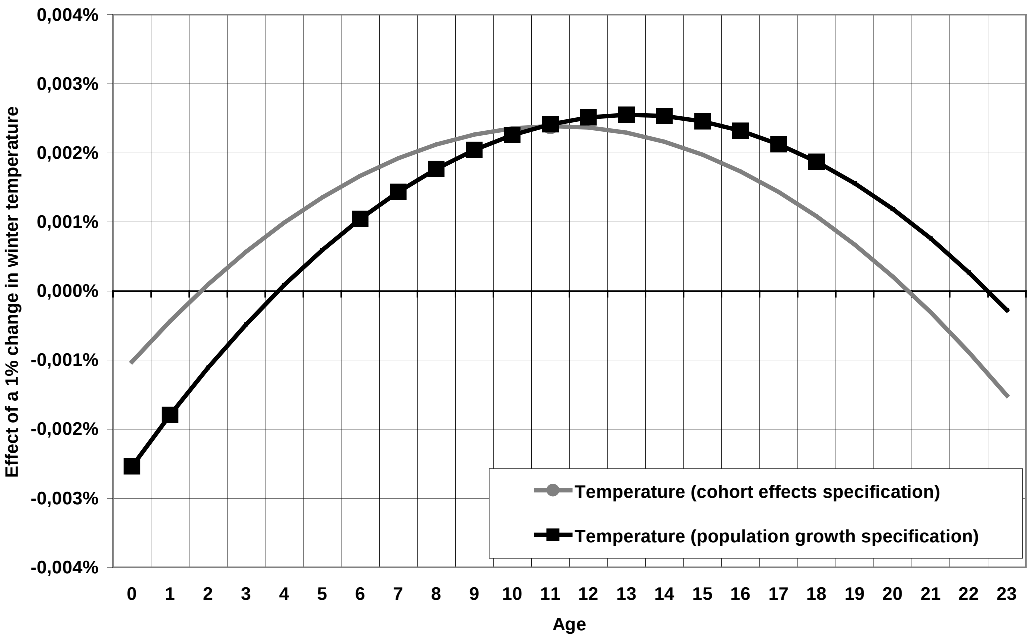


Figure 4. *Age-specific effects of winter temperature on height for french birth cohorts 1666–1763 (elasticities). The lagged coefficients are estimated without restrictions and freely varying parameters (top) and with a second-degree polynomial (below). Both models are controlling for either cohort effects or population growth. Dots indicate effects that are significant at least at the 10%-level in a one-sided t-test.*

The impact of famines on the development of physical stature and possible reasons for the improving nutrirional status in 18th century

Now knowing that the development of physical stature in early modern France was closely related to climate change and to grain price volatility, the significant increase in average height of Frenchmen during the 18th century can be described as the »Escape from Maunder Minimum«. At the end of the 17th century, when temperature had reached its minimum and also the state of agriculture was very poor[42], French adult men were extremly short, less than 161 cm on average. Thereafter their biological standard of living improved once this all-time minimum in temperature was passed. In a cyclical movement, average height increased during the first decades of the 18th century nearly in parallel to the significant improvement of climate: at first by some 5 cm to an average of about 165 cm for birth cohorts 1705–1715[43]. After having been subject to an intermediate drop that was caused perhaps by an severe dysentery epidemic in 1719[44] and by the outbreak of plague in 1720 (in Southern France)[45] and the severe nutritional crisis of 1740[46], height rose again by about 4 cm by the middle of the 18th century to an average of between 167–168 cm for birth cohorts 1740–1745. Thereafter, average height decreased again, but this fall was relatively small in comparison to the levels experienced in the late 17th century. This tendency of Frenchmen who were born after 1750 to grow shorter was paralled of decreases in height elsewhere in Europe, caused by worsening economic conditions. In France, the economy performed less well under the late Louis XV and under Louis XVI, whose reign started in 1774.

[42] There have been only two regions in which the overall status of agriculture was not as bad as it was in the rest of France: In Burgundy and Alsace, the agricultural output still grew due to reconstruction from the Thirty-Years-War. LE ROY LADURIE 1975, pp. 394–396. In addition to the very poor overall state of French agriculture at the end of the 17th century, the living standard was hampered severely by the subsistence crisis of 1693/94 that developed because of a series of poor harvests from 1691 to 1693. Cf. GOUBERT 1970 (Le «tragique» XVIIe siècle), pp. 329–365; BERGER 1978, pp. 101–127. Especially the extremely high amount of rainfall in late summer and early autumn 1692 had desastrous consequences for the harvest in that particular year. Cf. PFISTER 1988a, p. 41. See on subsistence crises in the era of Louis XIV in general MEUVRET 1977 / 1987 / 1988.

[43] This continous improvement only was interrupted for birth cohorts born around 1700, presumably due to the severe subsistence crisis of 1709/10 that had developed because of the extremely cold winter 1708/09. See e.g. LACHIVER 1991, LEBRUN 1980, pp. 205–234 and POUSSOU 1980, pp. 238–240.

[44] The dysentery epidemic had severe demographic consequences. It is estimated, that because of this epidemic about 50 percent of the population growth since 1710 has been lost. Cf. LACHIVER 1991, p. 480.

[45] Cf. FLINN 1979, pp. 131–148. In total about 120 000 people died from plague, the city of Marseille almost lost 50 percent of its inhabitants. Cf. LEBRUN 1980, p. 222.

[46] Cf. POST 1985.

For the whole period under consideration, famines developed periodically. They not only brought about excess mortality in the range of 6 to 7 percent in comparison to normal years[47], famines had a lasting effect for the nutrional status of Frenchmen and their standard of living. The assessment of average height reveals regular dips in the long-term development of physical stature for those cohorts born about 15–18 years before a major subsistence crisis. This clearly holds for the famines of 1693/94, 1709/10 and 1740, as can be seen from **Figure 5**, and is in accordance with the finding, that grain price effects were most important during late youth and adolescence. This also indicates, that the economic conditions that were experienced during the second decade of growth usually decreased average height permanently. The reason for that being probably that during adolescence the body grows substantially whereas at the same time the opportunity of catching up earlier growth deficits ceases more and more away with every year a person becomes older and not many such years to grow are left. This notwithstanding, the time series of French adult average heights also shows marked footprints of major famines for those birth cohorts experiencing the food shortages at very young ages (see also **Figure 5**). For instance, the significant increase of average height at the turn of the century fades for the birth cohorts after 1705. People who were born around 1705 experienced the severe famine of 1709/10 when they had been still very young. Also, in the beginning of the 1770's the living standard of Frenchmen was again hampered by a severe nutritional crisis. In addition to that, during the spring of 1775, e.g., the Paris Basin (*Île de France*) was the scene for numerous food riots, the so-called "Flour War" (*la guerre des farines*) that developed following the permission to freely circulate grain within the kingdom in the fall of 1774. The shortages of grain supply caused by this allowance negated the state's traditional responsability to protect the population from hunger and provoked the riots[48]. Until the revolution nutritional crises became more frequent again[49]. The welfare-decreasing effect of these developments is clearly seen for the last birth cohorts in the sample, those born around 1760.

[47] Cf. O'GRADA, CHEVET 2002, pp. 710.

[48] Cf. BOUTON 1993, p. xix. See also BOUTON 1990, pp. 735–754. There were about 300 riots in the region. Almost all local and regional grain markets were affected threatening the Paris grain supply system seriously. For a description of this system see KAPLAN 1984. For the situation during the »Flour War« around the town of Beauvais see SAMSON 1983.

[49] For the region of Burgundy see e.g. GIROD 1906, pp. i–xxiii and 1–145.

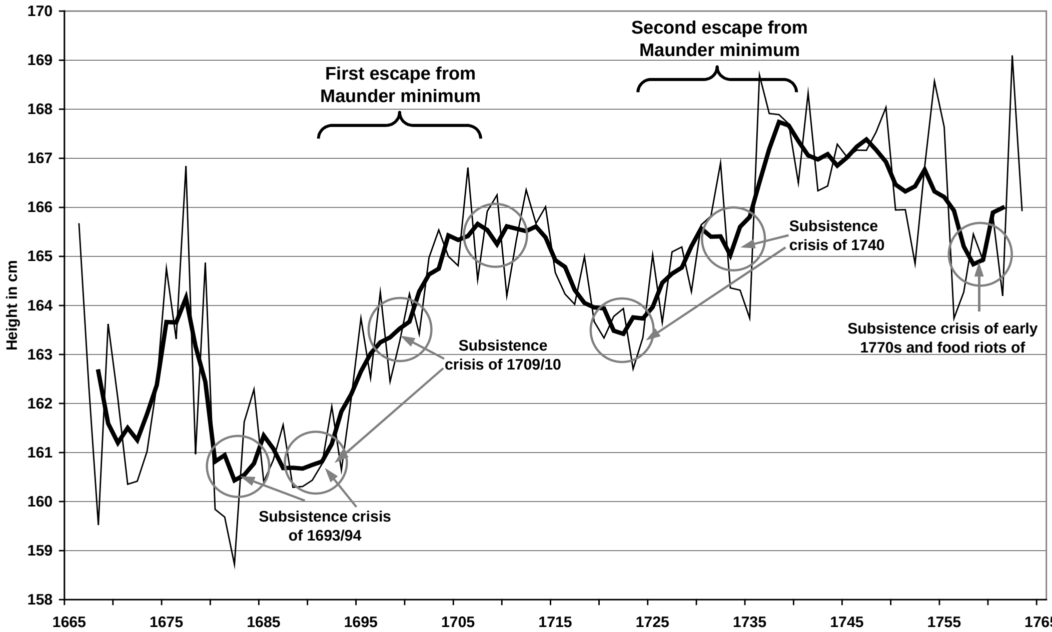


Figure 5. *Development of French male adult average height for birth cohorts 1666–1763 (bold line is centered 5-year moving average). Circles mark possible causes for decreasing average height.*
Source: Author's own drawing on the basis of French height data described in KOMLOS, HAU, BOURGUINAT 2003.

Although productivity of French agriculture in the Ancien Régime sufficed to provide the food requirements of a stagnant or only slowly growing population, there still were, as mentioned above, numerous subsistence crises[50]. The major part of the French population was economically dependent to the effect that they could not compensate the effect of a nutritional crisis with individual measures[51]. Thus, extreme weather conditions were a serious threat to the production of grain and food and forced many people below the level of subsistence. French agricultural productivity generally stagnated until the mid of the 18th century[52]. It seems to be obvious, that in the short term population growth shifted the demand for nutrients and thus caused an increase of prices. The growth of agricultural production in France at the end of the 17th and in the beginning of the 18th century was lower than population

[50] Cf. LE ROY LADURIE, GOY 1982.

[51] In the region of Beauvais, for instance the amount of contributions to pay for farmers was about 52 percent of their yield. Since another 20 percent were necessary for sowing, farming households had to live with slightly more than a quarter of their annual crop. Cf. GOUBERT 1960, pp. 180–181.

[52] The level of output in the late 17th century was between 25–40 percent of the average level reached between 1700 and 1789. Cf. LE ROY LADURIE 1975, pp. 394–396. On French Ancien Régime agriculture see in general DARRIÈRE 1958, pp. 317–344; SAINT-GERMAIN 1965; FORSTER 1970, pp. 1600–1615; LABROUSSE 1970 (Les «bons prix» agricoles du XVIII^{e} siècle, pp. 367–416), (L'expansion agricole: La montée de la production, pp. 417–471) and (Les ruptures périodiques de la prospérité: Les crises économiques du XVIII^{e} siècle, pp. 529–563); GINDRIN 1972, pp. 414–433; HUFTON 1974; LE ROY LADURIE 1974, pp. 1–27; BAULANT 1975, pp. 505–518; KAPLAN 1977, pp. 197–230; GOLDSMITH 1984, pp. 175–200; HOFFMAN 1996.

growth. It could not keep pace with the additional population. The growth rate of food supply is estimated to have been between 0.15 and 0.33 percent per year during the 18th century, whereas the annual population growth rate was about 0.3 to 0.35 percent[53]. Nevertheless, famines did become rarer in the first half of the 18th century. As consequence of the nutritional crises in the second half of the 17th century, the population still remained below the previous maximum level of 20–21 million people so that with the exemption of 1709/10 and 1740 a persistent severe nutritional crisis did not develop in spite of population growth[54]. Moreover, in the second half of the century, market integration[55] was boosted by the immense growth of overland traffic[56] and agricultural products could be distributed better than before[57].

The average population growth rate experienced by a birth cohort during its years of physical growth seems to have had a slightly positive long-term effect on the average height of that particular birth cohort. In most of the years in the 18th century the French population grew, even if this growth was small. Since in this period also average height increased, this result possibly is due to the fact, that in the first half of the 18th century the French population was recovering from the losses of the 17th century and still had not reached the critical size of about 20–21 million people. Thus, the agricultural production was high enough to feed a growing population, and in addition to that, the distribution of these products within the country improved in this period when many roads were constructed.

The different effects of population growth rates experienced in the year of birth show a more detailed picture of this mechanism. The reference cohorts are those in which population growth was either stagnating or shrinking, in birth years 1666–1679 population was shrinking in the order of 0.27 percent each year and in birth years 1690–1699 population growth was null. Cohorts were taller the more negative the rate of population growth in their year of birth was. For birth cohorts who experi-

[53] Cf. HOFFMAN 1996, p. 135.

[54] Cf. LE ROY LADURIE, GOY 1982, p. 174. On the demographic development see GOUBERT 1970 (La force du nombre, pp. 9–21), (Le régime démographique français au temps de Louis XIV, pp. 23–54) and (Révolution démographique au XVIIIe siècle?, pp. 55–84); DUPÂQUIER 1997, pp. 435-452.

[55] BAC, CHEVET, GHYSELS 2001, pp. 32–55, O'GRADA 2005, pp. 143–166, and O'GRADA, CHEVET 2002, pp. 706–733, show market integration for several French grain markets in 16th, 17th and 18th centuries.

[56] Cf. ARBELLOT 1973, pp. 765–791; LETACONNOUX 1906/07, pp. 409–445; LETACONNOUX 1908/09, pp. 97–114 and 268–292.

[57] French agriculture did not improve significantly in those times because of the inadequate internal communications and numerous inland tolls. A lot of different measures and weights made the exchange even more difficult. Thus, even with improving productivity, agricultural products could not be distributed adequately. Cf. KELLENBENZ 1976, pp. 236–237. In times of nutritional crises, regions were fairly isolated in choosing appropriate measures to confront the crisis. Cf. MICHAELOWA 2001, pp. 201–218.

rate of population growth in their year of birth was. For birth cohorts who experienced a medium growth rate of population in the birth year (up to 0.2 percent per year) a positive impact is estimated, thus population growth has had to be of optimal size in order to affect the biological standard of living positively. For those cohorts with high population growth (> 0.2 percent per year) rates in the year of birth, an effect on average height was virtually not existing. A higher growth rate meant an intertemporary strong contention for scarce food resources which then not shrinked the final average height in absolute terms, but reduced it in comparison to periods with population growth below 0.2 percent per year. Thus, once population grew with a rate greater than this threshold, living standards were decreased lastingly.

Conclusions

The analysis described in this paper has revealed significant direct and indirect welfare effects of climate anomalies for the French population in early modern times. The nutritional status of Frenchmen improved during the 18th century to a large extent in correspondence with improvements of climate. Especially warmer winter weather conditions can explain the subsequent shifts in average height that occurred for cohorts that were born in the first half of the 18th century, presumably by providing people with better living conditions during the winter.

The improvement of climate affected French male heights also indirectly via a more abundant food production. Although the improvement of climate also was responsible for richer harvests causing lower level of grain prices, this agricultural effect was partly compensated by two other effects that resulted form this first effect: Firstly, a low level of grain price made cereals more attractive to consume in comparison to proteins. This protected the majority of French from hunger during the first half of the 18th century, but had a dampening effect on physical growth, too, insofar as proteins are more coinducive to growth than calories. Secondly, because scarcities of basic cereals were reduced significantly, population started to grow even if slowly, which in turn tended to reduce average height in the long term. Thus, the height increasing effect of climate improvement was damped to some extent.

Age-specific effects of winter temperature and grain prices were largest during late youth and adolescence. Given the particular structure of the data and the method of polynomial distributed lags regression, the findings obtained make perfectly sense: redardation of growth in early childhood could be compensated during later stages of growth, especially during adolescence. For birth cohorts, who were faced with unfavourable climatic and economic conditions during adolescence, the catch-up growth was much more difficult, if not impossible. Thus, these birth cohorts were substantially stunted and detrimental effects of an unfavourable climate and a high level of grain prices are seen especially for the years of adolescence.

Concerning the effect of population growth, the analysis shows that it had a significant positive effect for cohort-specific average height, although this effect was quite small in relative absolute terms. However, estimates of population growth effects in the year of birth indicate that height dropped on average, once the growth of population accelerated. Therefore one may conclude that the French society at the beginning of the 18th century seems to have been on the eve of escaping from the Malthusian trap, although the negative feed-back effect of population growth on the standard of living could not be entirely left behind. The population was still recovering from the immense losses of the late 17th century, and once climate had started to improve sustainably, the supply of food became sufficient to prevent the most severe nutritional crises. In a situation like that, a slight growth of population did not have a profound effect on the biological standard of living.

Finally, the period between c. 1660 and c. 1760 was characterised by an extreme and unfavourable climate, indeed. Although temperatures were way below long-term standards, the climate became warmer during this particular century and in parallel to this upswing also the biological standard of living improved. Hence, the great subsistence crises that occurred between the end of the 17th century and the French Revolution still left their foodprint in the series of French heights. The impact of these crises, many of which were induced by climatic anomalies, can be very clearly seen by decreases in average height mainly among those cohorts that were born about 15–18 years before a crisis set off. However, that during the 18th century the threat of famine ceased and the long-term impact of a famine on welfare in general was smaller than it had been in the 17th century, was in part also because the infrastructure of France improved a lot and grain markets became more integrated, thus enabling the French society to cope better with food shortages and subsistence crises than before.

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