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THE BIOLOGICAL STANDARD OF LIVING IN A COLD CENTURY

Long-term Effects of Climate and the Economy on Average Height in Ancien Régime France*

Abstract: The change of human height over time is believed to reflect the long-term development of a population's net nutritional status. Although height is undoubtedly determined by changing economic conditions, the impact of climate should be taken into consideration, too: on the one hand side human growth is affected by climate directly through moderate temperatures enabling the human body to use calorie intake for growth instead of using it to maintain the body's basal metabolic rate. On the other hand, harvests and thus prices of nutrients are determined by climatic conditions and therefore have an indirect impact on human growth. Between c. 1660 and c. 1760 Europeans went through the coldest period of the last millenium. By using a series of French adult heights, the consequences of changes in climate for the human growth process are estimated. With the model applied herein age-specific magnitudes of climatic and economic conditions on the human growth process are calculated. Moreover, the total effect of climate is decomposed into direct and indirect effects. The latter were mediated through prices of nutrients. The estimations show, that the direct effect of winter temperature on height was significant in Ancien Régime France. As expected, warmer winter temperatures fostered human growth with the strongest influence having been at ages 13–17. So once the climate had started to become more moderate, with relatively warm summers and an optimal degree of humidity, it was able to increase the biological standard of living also indirectly, because harvests were richer and grain prices were lower, which in turn increased consumption and therefore average height. Peak influences were at ages 13–17, too, thus indicating that the second decade of human growth was most important for the terminal height that was reached by a birth cohort.

Introduction

Within the hundred years between c. 1660 and c. 1760 the population of Europe experienced the coldest climate period it has seen ever since the year 1000. Temperature at the end of the so-called »Little Ice Age« on average was between 0.25 °C and 0.5 °C below the long-term mean. In addition, the amount of rainfall was much higher than normal[1]. Temperature has been at low levels before, for instance towards

* The author is grateful to John Komlos for suggestions and comments and for having provided him with the time series of French adult average heights. The author gratefully acknowledges the generous help of Christian Pfister, who provided climate data for Switzerland, and that of Philipp T. Hoffman, who provided data on prices and the cost of living in Paris during the 17th and 18th centuries. The author is also grateful to Marek Brabec, Jan Jacobs and Stephan Klasen for their comments on an earlier version of this paper.

1 R. Glaser, Klimageschichte Mitteleuropas. 1000 Jahre Wetter, Klima, Katastrophen, Darmstadt 2001, pp. 176–177, p. 181 (data for Central Europe). See also C. Pfister, Wetternachhersage. 500 Jahre Klimavariationen und Naturkatastrophen (1496–1995), Bern et al. 1999, E. Le Roy Ladurie, Histoire du climat depuis l'an mil, 2 vols., Paris 1987. In the period 1666–1788, e. g., Swiss winter temperature, recontructed with qualitative information from Basel, deviated by

the end of the 16th century, but the persistence of adverse climatic conditions during late 17th and early 18th centuries was unprecedented. Since Europeans were faced about 4 to 5 generations with such an unfavourable climate, the effects of these climatic conditions on physical stature 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«[2], this relationship was recognised in the discussion on political economy in France during the 18th century[3]. But also empirical evidence was already published by that time. In 1766, the French scholar Louis Messance[4] published a study on the population of France (»Recherches sur la population de la France«), in which he showed that the relationship between grain prices, illness and mortality was negative indeed[5]. And in fact, the conclusions drawn by Messance from the analysis of annual data from Rouen for the period 1680–1699 can be reproduced by using the modern analytical instruments of scatter diagram and regression analysis *(Figure 1)*[6].

Nevertheless, illness and mortality 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 to that, 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, these long-term consequences can be traced by studying time trends in human growth[7]. Even if young people did not die

-0.241 °C 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 °C. In this particular period even summer temperatures were significantly lower than normal (about -0.171 °C, all deviations are calculated on the basis of the 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 °C below today's level. Cf. M. LACHIVER, Les années de misère. La famine au temps du Grand Roi 1680–1720, Paris 1991.

2 T. R. MALTHUS, An Essay on the Principle of Population, 1798 (edition New York 1976).

3 R. GÖMMEL, R. KLUMP, Merkantilisten und Physiokraten in Frankreich, Darmstadt 1994.

4 On Louis Messance see E. BRIAN, C. THÉRÉ, Fortune et infortune de Louis Messance (2 janvier 1734–19 avril 1796), in: Population 53 (1998) pp. 45–92.

5 *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.* L. MESSANCE, Réflexions sur la valeur du bled tant en France qu'en Angleterre depuis 1674 jusqu'en 1764, appendice aux *Recherches sur la population des Généralités d'Auvergne, de Lyon et de Rouen, et de quelques provinces et villes du Royaume*, Paris 1766, pp. 280–292 [printed in P. GUILLAUME, J.-P. POUSSOU (eds.), Démographie historique, Paris 1970, pp. 163–165], p. 165.

6 Messance, who used way less sophisticated methods, 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. Cf. MESSANCE (see note 5), p. 163. Regressing the number of deaths and the number of ill persons on wheat price and on squared wheat price shows that variations of these measures of the standard of living are explained by about 82.5% (deaths) and by ca. 68.6% (ill persons) by varying wheat prices.

7 J. M. TANNER, Introduction: Growth in Height as a Mirror of the Standard of Living, in: J. KOMLOS (ed.), Stature, Living Standards and Economic Development. Essays in Anthropometric History,

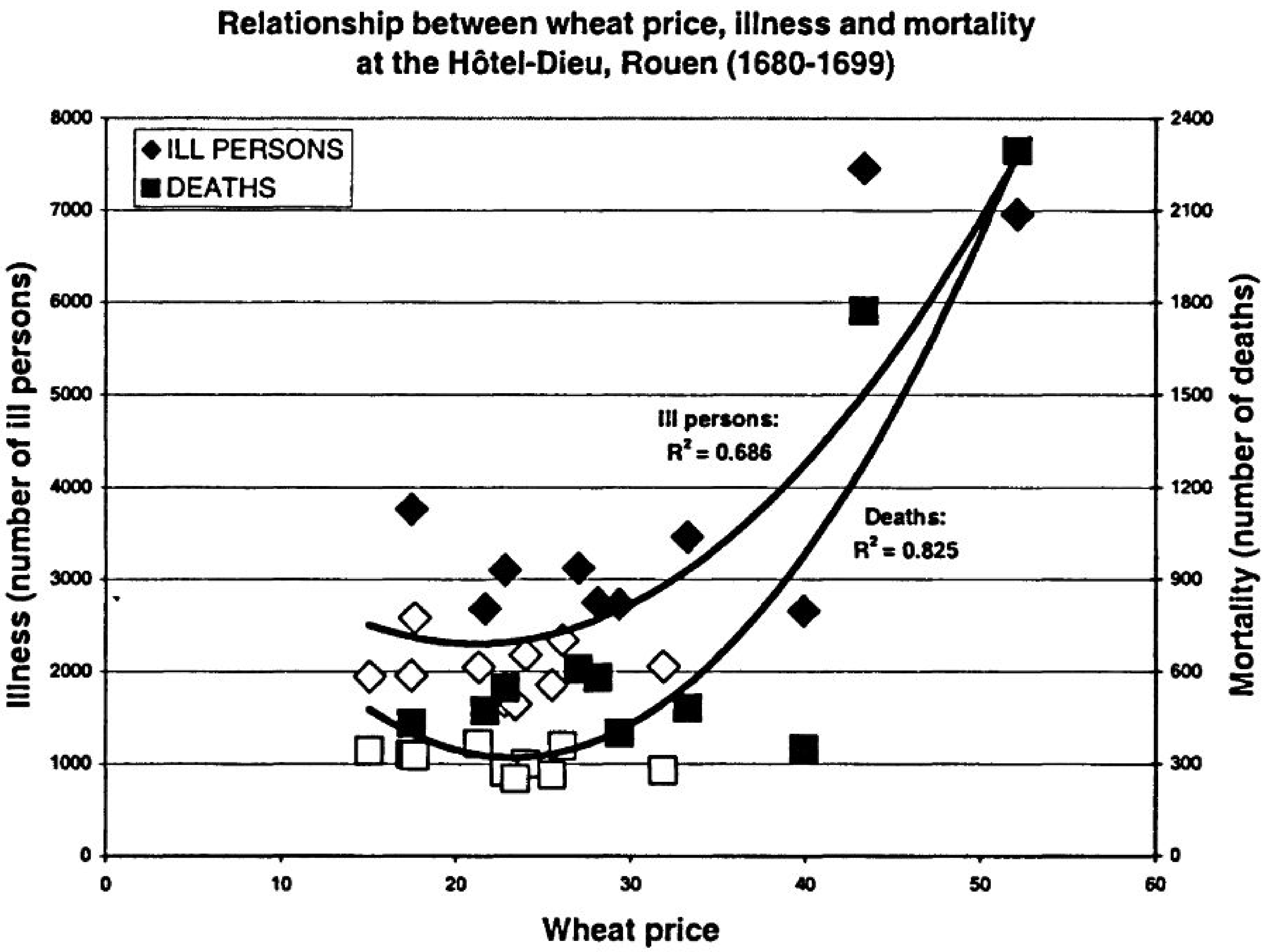


Figure 1: Relationship between wheat price and indicators of the standard of living in late 17th century France (city of Rouen, 1680–1699). Black boxes indicate those years which originally were classified by Messance as worse.
Source: Author's own calculations on the basis of Messance's data.

or did not become seriously ill during a period of food shortages and high grain prices, such economic situations 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[8]. Thus, the impact of bad economic conditions experienced during the growth process was stored permanently in the memory of physical stature and is expressed as stuntedness. In a macro-level framework unfavourable economic and environmental conditions reduced the average height of a birth cohort.

Chicago and London 1994, pp. 1–6; T. Cuff, Historical Anthropometrics – Theory, Method, and the State of the Field, in: J. Komlos (ed.), The Biological Standard of Living on Three Continents. Further Explorations in Anthropometric History, Boulder et al. 1995, pp. 1–15; R. H. Steckel, Stature and the Standard of Living, in: Journal of Economic Literature 33 (1995) pp. 1903–1940; U. Woitek, Heights Cycles in the 18th and 19th Centuries, in: Economies and Human Biology 1 (2003) pp. 243–257.

8 J. Komlos, M. Hau, N. Bourguinat, The Anthropometric History of France, in: European Review of Economic History 7 (2003) pp. 159–189.

The impact of climate on height

There is strong empirical evidence, that a population's biological standard of living, measured in terms of average height, is generally affected by the climatic conditions the population lives in. Steckel compares the course of temperature during the last millenium (c. 1000–2000) with the development of human height in Northern Europe. The 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[9]. 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 can be shown with the height records of soldiers serving in the French army starting with birth cohorts of 1666[10]. The rapid increase of their average height at the turn of the 18th century coincides with the end of the so-called Maunder Minimum[11], a period of extremly cold years stretching from c. 1675 to c. 1715[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].

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[14], the net nutritional status was indirectly influenced by climate through abundance or scarcity of grain and other food products. The production of proteins (milk and meat) was also affected by climate because the quality of pastures relied on how long

9 R. H. Steckel, New Light on the ›Dark Ages‹: The Remarkably Tall Stature of Northern European Men during the Medieval Era, in: Social Science History 28 (2004) pp. 211–229.

10 Komlos, Hau, Bourguinat (see note 8).

11 This period is named in honour of E. Walter and Annie S. D. Maunder, englisch 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. For the Maunder Minimum see e. g. B. Frenzel, C. Pfister, B. Gläser (eds.), Climatic Trends and Anomalies in Europe 1675–1715, Stuttgart 1994, pp. 151–171 (Paleoklimaforschung, 13), R. Glaser, Data and Methods of Climatological Evaluation in Historical Climatology, in: Historical Social Research 21/4 (1996) pp. 56–88; Glaser (see note 1), pp. 175–176, R. Glaser, C. Beck, Weather and Climate During the Maunder Minimum 1675–1715 in Central Europe. ADVICE Working Paper 3, University of Würzburg, April 1997.

12 See below and also J. Komlos, U. C. Ewert, Global Warming and the Secular Increase in Human Height. Evidence from the End of the Little Ice Age in France, Working Paper, University of Munich, 2002 (19 pp.).

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. J. Baten, Climate, Grain Production and Nutritional Status in Southern Germany during the XVIIIth Century, in: The Journal of European Economic History 30 (2001) pp. 9–47, p. 34, Figure 8.

14 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. C. Pfister, Fluctuations climatiques et prix céréaliers en Europe du XVIe au XXe siècle, in: Annales. Économies. Sociétés. Civilisations 43 (1988) pp. 25–53, pp. 34–35.

they were covered by snow during winter and on when the grass began to grow in the spring[15]. France in the late 17th and early 18th centuries was not an exception. 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 numerous subsistence crises[16]. 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[17]. 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[18]. In the second half of the century, market integration was boosted by the immense growth of overland traffic[19] and agricultural products could be distributed better than before[20].

15 C. PFISTER, Klimageschichte der Schweiz 1525–1860. Das Klima der Schweiz von 1525–1860 und seine Bedeutung in der Geschichte von Bevölkerung und Landwirtschaft, Bern, Stuttgart ³1988, pp. 38–39 and BATEN (see note 13), p. 30.

16 E. LE ROY LADURIE, J. GOY, Tithe and Agrarian History from the Fourteenth to the Nineteenth Centuries. An Essay in Comparative History, Cambridge et al. 1982.

17 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. P. GOUBERT, Beauvais et le Beauvaisis de 1600 à 1730, 2 vols., Paris 1960, pp. 180–181.

18 The level of output in the late 17th century was between 25–40 percent of the average level reached between 1700 and 1789. Cf. E. LE ROY LADURIE, De la crise ultime à la vraie croissance 1660–1789, in: Histoire de la France rurale, vol. 2, ed. by E. LE ROY LADURIE, Paris 1975, pp. 359–599, pp. 394–396. On French Ancien Régime agriculture see in general A. DARRIÈRE, Feudal Incomes and Demand Elasticity for Bread in Late Eighteenth-Century France, in: Journal of Economic History 18 (1958) pp. 317–344; J. SAINT-GERMAIN, La vie quotidienne en France à la fin du grand siècle, Paris 1965; R. FORSTER, Obstacles to Agricultural Growth in Eighteenth-Century France, in: American Historical Review 75 (1970) pp. 1600–1615; E. LABROUSSE, Les »bons prix« agricoles du XVIIIe siècle (p. 367–416), L'expansion agricole: La montée de la production (pp. 417–471) and Les ruptures périodiques de la prospérité: Les crises économiques du XVIIIe siècle (pp. 529–563), in: F. BRAUDEL, E. LABROUSSE (eds.), Histoire économique et sociale de la France, vol. 2: Des derniers temps de l'âge seigneurial aux préludes de l'âge industriel (1660–1789), Paris 1970; C. GINDRIN, Le pain de Gonesse à la fin du XVIIe siècle, in: Revue d'histoire moderne et contemporaine 19 (1972) pp. 414–433; O. W. HUFTON, The Poor in Eighteenth-Century France, 1750–1789, Oxford 1974; E. LE ROY LADURIE, Pour une modèle de l'économie rurale française au XVIIIe siècle, in: Cahiers d'histoire 19 (1974) pp. 1–27; M. BAULANT, Niveau de vie des paysans autour Meaux en 1700 et 1750, in: Annales. Économies. Sociétés. Civilisations 32 (1975) pp. 505–518; S. L. KAPLAN, Lean Years, Fat Years: The ›Community‹ Granary System and the Search for Abundance in Eighteenth-Century France, in: French Historical Studies 10 (1977) pp. 197–230; J.-L. GOLDSMITH, The Agrarian History of Preindustrial France: Where Do We Go from Here?, in: Journal of European Economic History 13 (1984) pp. 175–200; P. T. HOFFMAN, Growth in a Traditional Society. The French Countryside, 1450–1815, Princeton 1996.

19 G. ARBELLOT, La grande mutation des routes de France au milieu du XVIIIe siècle, in: Annales. Économies. Sociétés. Civilisations 29 (1973) pp. 765–791; J. LETACONNOUX, La question des subsistances et du commerce des grains en France au XVIIIe siècle, in: Revue d'histoire moderne 8 (1906/07) pp. 409–445; J. LETACONNOUX, Les transports en France au XVIIIe siècle, in: Revue d'histoire moderne et contemporaine 11 (1908/09) pp. 97–114 and 268–292.

20 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. H. KELLENBENZ, The Rise of the European Economy. An Eco-

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. The level of winter temperature seems to play a fundamental role for the explanation of inter-cohort height differentials. An extremely cold winter for instance obviously was 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[21]. Therefore, more favourable winter weather conditions fostered human growth by suppressing inhibiting factors.

Thus, climate affects height both directly and indirectly. In this paper a causal model for the impact of prices and temperature on average height is proposed, that allows to measure economic effects on physical stature by controlling for changes in climate. In particular, the aggregate influence of climatic conditions on height in Ancien Régime France (17th–18th centuries) is decomposed into direct and indirect effects. Thereafter, estimations of age-specific effects of climatic conditions on height are presented.

The development of physical stature in Ancien Régime France

With a series of average height of French male adults born between 1666 and 1763[22] *(Figure 2)*, it becomes possible to assess the effects that changing economic as well as climatic conditions had on the development of physical stature over the course of 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. This period is of particular interest, because it marks the Maunder Minimum and is characterised by a beginning secular improvement of climate, especially of temperature during the first decades of the 18th century[23].

At the end of the 17th century, when temperature had reached its minimum and also the state of agriculture was very poor[24], French adult men were extremly short,

nomic History of Continental Europe from the fithteenth to the eighteenth Century, London 1976, pp. 236–237. In times of nutritional crises, regions were fairly isolated in choosing appropriate measures to confront the crisis. Cf. A. Michaelowa, The Impact of Short-term Climate Change on British and French Agriculture and Population in the First Half of the 18th Century, in: P. Jones, A. Ogilvie, T. Davis (eds.), History and Climate. Memories of the Future?, New York 2001, pp. 201–218.

21 Komlos, Hau, Bourguinat (see note 8) and Komlos, Ewert (see note 12).

22 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 (see note 8).

23 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 (see note 1), p. 181; R. Glaser, U. Beyer, C. Beck, Die Temperaturentwicklung in Mitteleuropa seit dem Jahr 1000, in: Tübinger Geographische Studien 125 (1999) pp. 23–46.

24 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. Cf. Le Roy Ladurie 1975 (see note 18) pp. 394–396. In addition to

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 cms to an average of about 165 cm for birth cohorts 1705–1715[25]. After having been subject to an intermediate drop that was caused perhaps by an severe dysentery epidemic in 1719[26] and by the outbreak of plague in 1720 (in Southern France)[27] and the severe nutritional crisis of 1740[28], height rose again by about 4 cms 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 French men 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. 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

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. P. GOUBERT, Le »tragique« XVIIe siècle, in: F. BRAUDEL, E. LABROUSSE (eds.), Histoire économique et sociale de la France, vol. 2: Des derniers temps de l'âge seigneurial aux préludes de l'âge industriel (1660–1789), Paris 1970, pp. 329–365; P. BERGER, French Administration in the Famine of 1693, in: European Studies Review 8 (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 (see note 14), p. 41. See on subsistence crises in the era of Louis XIV in general J. MEUVRET, Le problème des subsistances à l'époque de Louis XIV. Vol. 1: La production des céréales dans la France du XVIIe et du XVIIIe siècle (Paris 1977); vol. 2: La production des céréales et la société rurale (Paris 1987); vol. 3: Le commerce des grains et la conjoncture (Paris 1988).

25 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 (see note 1), F. LEBRUN, Les crises démographiques en France aux XVIIe et XVIIIe siècles, in: Annales. Économies. Sociétés. Civilisations 35 (1980) pp. 205–234 and J.-P. POUSSOU, Les crises démographiques en milieu urbain: l'exemple de Bordeaux (fin XVIIe–fin XVIIIe siècle), in: Annales. Économies. Sociétés. Civilisations 35 (1980) pp. 235–252, pp. 238–240. The German sister-in-law of King Louis XIV, Elisabeth Charlotte, Princess Palatine, who was married to his brother, the Duke of Orléans, described the situation in Versailles as follows: *Mein tag des lebens habe ich keinen solchen rauen winter erlebt wie dießer; der wein erfriert in den bouteille* (cited from J. Voss, Liselotte von der Pfalz [1652–1722]. Eine europäische Fürstin und ihr Zeitalter, in: Pfälzer Heimat 52 [2001] pp. 45–60, p. 54).

26 The dysentery epidemic had severe demographic consequences. It is estimated, that because of this epidemic about 50 percent of the population growth since 1710 were lost. Cf. LACHIVER (see note 1), p. 480.

27 M. W. FLINN, Plague in Europe and the Mediterranean Countries, in: The Journal of European Economic History 8 (1979) pp. 131–148. In total about 120000 people died from plague, the city of Marseille almost lost 50 percent of its inhabitants. Cf. F. LEBRUN (see note 25), p. 222.

28 J. D. POST, The Last Great Subsistence Crisis in the Western World, Baltimore 1977; J. D. POST, Food Shortage, Climatic Variability, and Epidemic Desease in Preindustrial Europe: The Mortality Peak in the Early 1740s, Ithaca 1985.

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[29]. Until the revolution nutritional crises became more frequent again[30].

In general, the assessment of average height reveals regular dips in the long-term development of height about 5–10 years before a major subsistence crisis. This is an indication, that economic conditions experienced during the second decade of human growth decreased average height permanently. The reason for that being

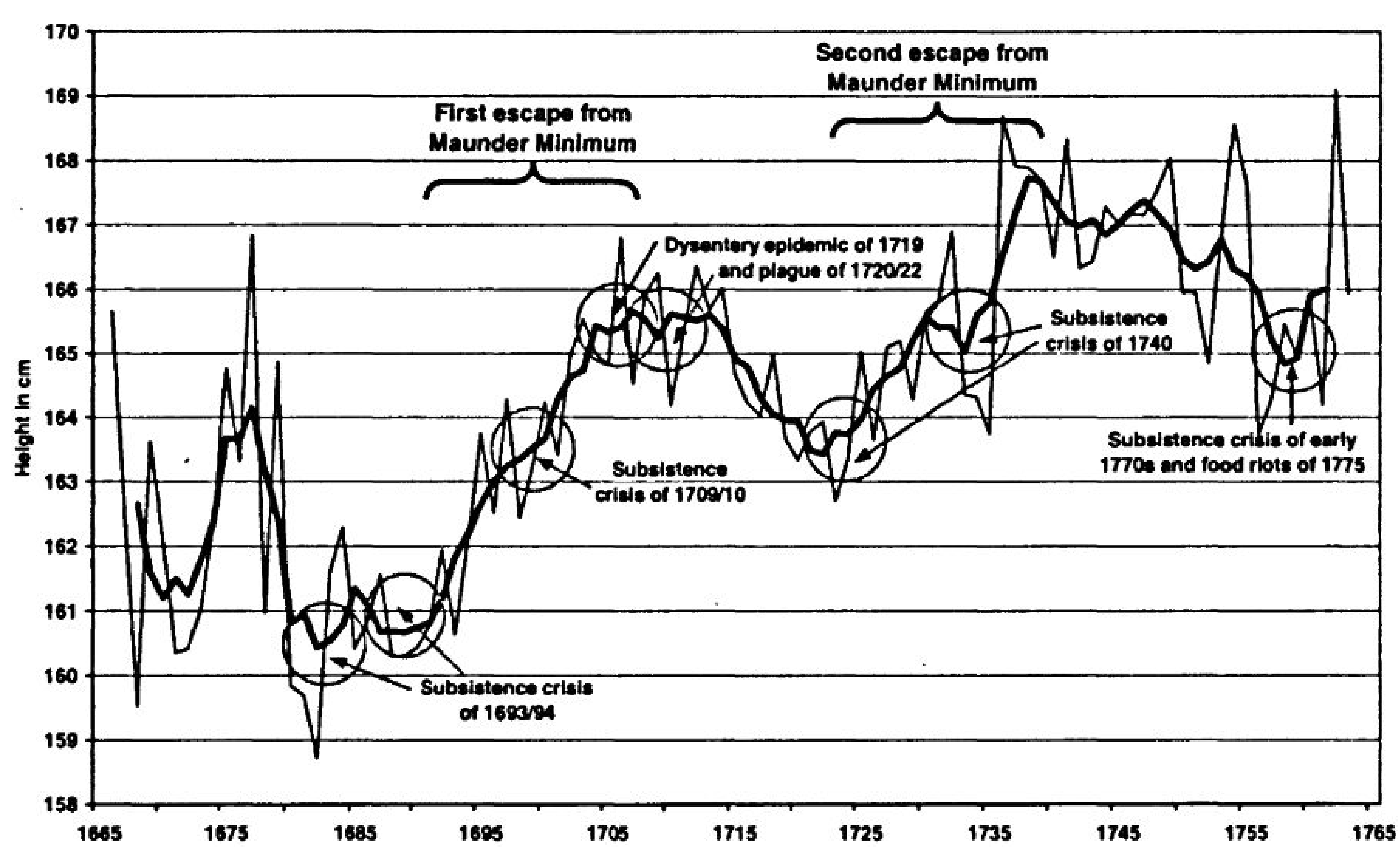


Figure 2: Development of French male adult average height for birth cohorts 1666–1763 (bold line is a centered 5-year moving average). Circles mark possible causes for decreasing average height.
Source: Author's own drawing on the basis of French height data described in Komlos, Hau, Bourguinat (see note 8).

29 C. A. Bouton, The Flour War. Gender, Class, and Community in Late Ancien Régime French Society, Pennsylvania 1993, p. xix. See also C. A. Bouton, Gendered Behavior in Subsistence Riots: The Flour War of 1775, in: Journal of Social History 23 (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 S. L. Kaplan, Provisioning Paris: Merchants and Millers in the Grain and Flour Trade During the Eighteenth Century, Ithaca 1984. For the situation during the »Flour War« around the town of Beauvais see R. Samson, La guerre des farines dans le Beauvaisis 1775, Beauvais 1983.

30 For the region of Burgundy see e. g. P.-E. Girod, Les subsistances en Bourgogne et particulièrement à Dijon à la fin du XVIII[e] siècle (1774–1789), in: Revue bourguignonne de l'enseignement supérieur 16 (1906) pp. i–xxiii and pp. 1–145.

probably that during adolescence the body grows substantially whereas at the same time the opportunity of catch-up growth ceases more and more away with every year a person becomes older and not many such years to grow are left.

The French height data is used herein in two ways: Firstly, a causal path system is estimated on the basis of decennial averages to identify the interplay between winter temperature, prices for nutrients, population growth and heights. Secondly, the annual height data is taken for the estimation of age-specific effects of both winter temperature and grain price within a polynomial distributed lags model.

The interplay between height and climate – a causal path model

A causal system is assumed in order to model the complex interaction between climate and average height *(Figure 3).* Within this system indirect effects of climate on height are distinguished from direct effects. The decennial average of height (HEIGHT) is related directly to lagged winter temperature (TEMP), lagged prices for nutrients (GRAIN, BREAD, PROTEINS) and lagged population growth rates (PGROWTH)[31]. In addition to the multiple regression approach, this formulation in terms of a causal path system makes it possible to identify indirect effects of climate, measured in terms of winter weather conditions, on average height. The correlation coefficient of $r = 0.72$ between decennial averages of winter and summer temperatures between 1670–1679 and 1780–1789 indicates that winter temperature is a sufficient proxy for overall climatic conditions.

Direct and indirect effects of temperature on human height are estimated using an interdependent equations approach. In the underlying causal system the latter effect is being mediated by the other variables in the model. The model is formulated in 5 equations: one equation for each endogenous variable. Only the index of winter temperature is assumed to be exogenous[32]. Detrended natural logarithms of all vari-

31 Due to limited availability of data for some indicators, aggregation was necessary and all variables are used as decennial averages from 1670–1679 to 1780–1789. TEMP: decennial average of Swiss winter temperature index (cf. PFISTER [see note 15] and PFISTER [see note 14], p. 31), annual data were provided by Christian PFISTER) are used to approximate the winter weather conditions in France. This index is constructed such that a situation similar to the long term »normal« situation referring to the period 1901–1960 is indicated with 0 and deviations from this long-term average are scaled in 1/3 steps either up to +3 (very warm winter) or down to -3 (very cold winter). Since for the reference period 1901–1960 both index values and temperatures measured in °C are known, index values for past centuries can be converted into deviations (in °C) from the long-term temperature mean. For regression purposes one either can use index values or converted temperature deviations, because the latter simply are linear transformations of the former. GRAIN and BREAD: decennial geometric averages of grain and bread consumer price indices for Paris. PROTEINS: average of decennial geometric averages of Paris consumer price indices for dairy, meat and fish (these data were provided by Philipp T. HOFFMAN). PGROWTH: population growth rates for France in the 17th and 18th centuries, calculated from population figures published by J. DUPÂQUIER, La population française aux XVIIe et XVIIIe siècles, Paris 1979). Average height was shifted forward on the time axis by 20 years in order to model the lagged influence of control variables. The value for decennial average height in use for 1700–1709, e. g., is calculated out of the averages of birth cohorts from 1680–1689. All regressors in the height regression are lagged by one decade.

32 Because the causal system has a recursive structure, each equation can be estimated separately with *Ordinary Least Squares* (OLS) without any loss of efficiency.

ables except population growth are used for the estimation. Thus, regression coefficients are elasticities[33]. The development of decennial averages of height is explained by levels of control variables one decade earlier. By this modelling strategy the dynamic character of the interaction between climate (temperature), the economy and the biological standard of living can be included, although it obviously simplifies the enduring influence of climatic and economic conditions over the course of the human growth process.

The model includes a causal path leading from prices for nutrients to population growth, but it does not encompass feed-back effects of population growth on any of the price variables. Of course, this is a simplification of a very complex causal relationship. 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 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[34]. 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[35]. Thus, it seems to be more important in this context to concentrate on the effect of population growth on height, because, with a given amount of nutritional resources, the existence of more individuals might have induced sufficient competition for these resources to reduce the average level of food consumption, and thereby might have reduced heights[36].

33 They show the percentage change in a dependent variable caused by a one-percent change in an independent variable. Only for population growth rate the meaning is a little bit different. For this particular variable which is measured in percentage points, estimated coefficients represent either a percentage change due to a change of growth rate in the order of one percentage point (in the regression for HEIGHT) or a change of percentage points of population growth rate following a one percent change of explanatory variables (in the regression for PGROWTH). The formulation of equations as multiplicative models stems from the assumption that neither height nor prices of nutrients are related linearly to the level of temperature.

34 Hoffman (see note 18), p. 135.

35 Le Roy Ladurie, Goy (see note 16), p. 174. On the demographic development see P. Goubert, 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), in: F. Braudel, E. Labrousse (ed.), Histoire économique et sociale de la France, vol. 2: Des derniers temps de l'âge seigneurial aux préludes de l'âge industriel (1660–1789), Paris 1970; J. Dupâquier, La France avant la transition démographique, in: J.-P. Bardet, J. Dupâquier (eds.), Histoire des populations de l'Europe, Paris 1997, vol. 1, pp. 435–452.

36 In addition by focusing on the effect of nutrient prices on population growth, and disregarding feedback effects, the system reduces to a recursive system, which makes the identification and estimation of parameters much simpler.

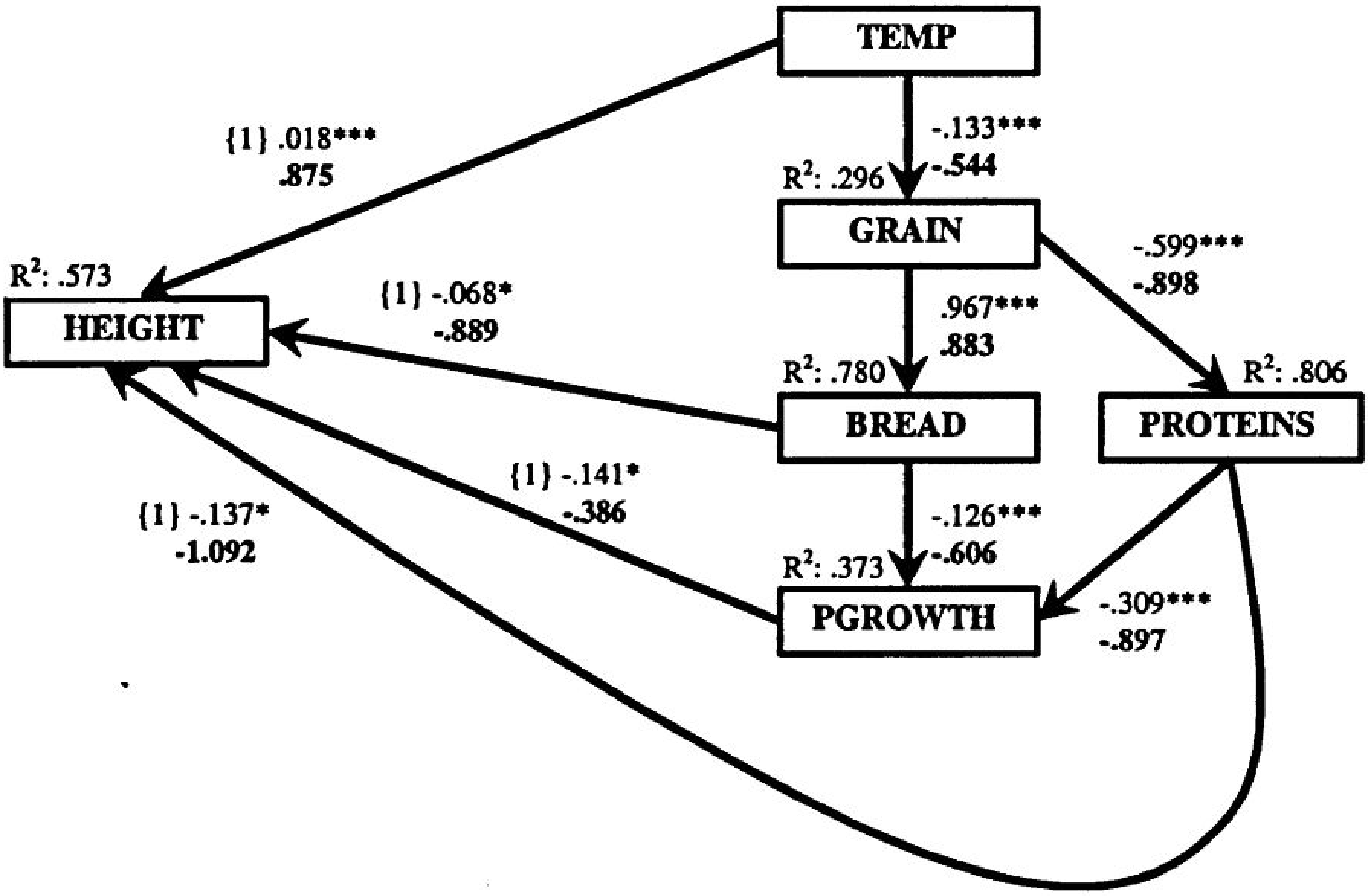


Figure 3: Causal diagram of interrelations between climate, economy, population and the net nutrional status. For each regression the coefficient of determination, elasticities and standardized elasticities (path coefficients) are reported. Lagged effects of previous decade are indicated by {1}. Significance levels of one-tailed t-tests are denoted with ***($p \leq 0.01$), **($p \leq 0.05$) and *($p \leq 0.10$).

The standardized regression coefficients (*path-coefficients*[37]) can be used to decompose within a path analysis[38] the bivariate correlation between the index of winter temperatures and average height into direct, indirect and non-causal effects (*Figure 3* and *Table 1*, path coefficients are in bold). This indicates how much of the bivariate correlation between average heights and lagged winter temperatures were due to direct and indirect causal effects or to other factors not incorporated into the model. According to the so-called path theorem path coefficients have to be multiplied along the paths in order to obtain indirect effects, and the bivariate correlation then can be written as the sum of causal and non-causal effects. The positive and significant direct effect *(0.875)* of the lagged winter temperatures on height is larger than originally indicated by the bivariate correlation *(r = 0.636)*. Since the indirect effects taken together almost cancel out each other, the total causal effect of *0.826* is comparable in magnitude to the direct effect of temperature. This implies that the direct effect of winter temperatures on height dominates even if controlling for the

37 Statistically, path coefficients are identical with standardized regression coefficients. Thus, the path coefficients can easily be calculated from the regression coefficients obtained by OLS.

38 For the concept of path analysis see e. g. H. M. Blalock, Causal Inferences in Nonexperimental Research, Chapel Hill 1964; O. D. Duncan, Path Analysis, in: American Journal of Sociology 72 (1966) pp. 1–15; R. Boudon, A New Look at Correlation Analysis, in: H. M. Blalock, A. B. Blalock (eds.), Methodology in Social Research, New York et al. 1968.

variation of all other variables in the model. Thus, the hypothesis that conditions of climate are directly responsible for time trends in human growth is supported.

This finding can be specified by the interpretation of estimated elasticities. With the assumed multiple regression model for the log of French average height about 57.3 percent of the variation are explained by the regressors. All parameter estimates for independent variables are significant and have the expected sign: Moderate winter temperatures had a pronounced positive effect for average heights: a one-percent increase in the index of winter temperatures led to a 0.018 percent increase of average heights a decade later. In contrast, high bread and protein prices reduced average height by 0.068 (BREAD) and 0.137 (PROTEINS) percent per one-percent increase. Protein prices had a greater impact on height than those of bread, which is in accordance with expectations. Notably, an increase in the rate of population growth in the order of one percentage point reduced average heights by 0.141 percent in the following decade.

	Elasticities	*Path-Coefficients*
Pearson's r		**0.636**
Direct effect	0.018	**0.875**
Indirect effects:		
(a) via GRAIN{1} and BREAD{1}	0.009	**0.427**
(b) via GRAIN{1}, BREAD{1} and PGROWTH{1}	-0.002	**-0.534**
(c) via GRAIN{1} and PROTEINS{1}	-0.011	**-0.112**
(d) via GRAIN{1}, PROTEINS{1} and PGROWTH{1}	0.003	**0.170**
Total (causal) effect	0.017	**0.826**
Non-causal effect		**-0.190**

Table 1: Direct and indirect elasticities and decomposition of causal effects of lagged winter temperature (TEMP) on french average adult heights.

With the analysis of paths of the causal system also indirect elasticities of height due to a change in winter temperature can be derived. In addition to the positive direct impact of winter temperatures on height, four indirect effects can be calculated from the parameter estimates of the causal system, simply by multiplying the estimated elasticities along the causal paths that lead from the temperature variable to the height variable:

(a) Higher winter temperatures reduced the propensity of harvest failures, therefore lowered prices of grain and bread, which in turn had a positive effect on the biological standard of living. Bread then was cheaper and therefore a higher amount could be consumed. A one-percent increase in temperatures led to a 0.009-percent increase in average height via this causal path[39].

39 *-0.133 x 0.967 x -0.068 = 0.009.*

(b) Lower bread prices stimulated population growth in the long run, which in turn lowered average human height. Via this more complex causal pathway a one-percent increase of winter temperatures led to a 0.002-percent decrease in average height[40]. Yet, the net effect of both paths is still positive *(0.007)*.

(c) If prices for proteins are included into the indirect causal effect of winter temperatures, indirect elasticities of roughly the same magnitude, but with opposite sign are obtained. Higher grain prices due to a lower winter temperature (and therefore to a poorer harvest) resulted in lower prices for proteins. The correlation between grain prices and prices for proteins was negative, presumably because households had a price inelastic demand for grain and bread below their subsistence level and therefore had to spend more of their fixed income on grain and bread in order to keep caloric intake constant[41]. In turn, this calorie constraint reduced the demand for such more expensive food items as milk, meat and fish. As a consequence of that the price of proteins decreased[42]. This mechanism is of importance, because low protein prices increased average height strongly. Thus, a one-percent increase in winter temperatures resulted in a 0.011-percent decrease in height through the mediation of grain prices and prices for proteins[43].

(d) Again, the population growth rate can be incorporated into the effect, with the result, that negative consequences of high protein prices could be partially damped, insofar as high protein prices slowed down population growth. Now a one-percent increase in winter temperatures meant a 0.003-percent increase of human average height[44]. But, the net effect of these two paths remains still negative *(-0.008)*.

Since high prices of nutrients lowered population growth, the negative impact of prices on heights was attenuated to some extent by the lower population growth rate. By comparing both aggregate indirect effects one can conclude that the positive indirect effect of winter temperature via grain and bread prices was overcompensated by the negative indirect effect due to higher protein prices[45]. This indicates how important the availability and the price level of proteins for the biological standard of living in Ancien Régime France was. Apart from that, the estimations show, that the improvement of climate in Western and Central Europe during the early

40 $-0.133 \times 0.967 \times -0.126 \times -0.141 = -0.002$.

41 Also shifts on the demand side could have been responsable for the negative correlation between grain price and price of proteins. Given an almost fixed total potential of agricultural production and assuming that farmers were sufficiently flexible in deciding on their production, a signal of increasing prices of either grain or protein rich food products presumably caused some farmers to substitute the production of the now more profitable food product for the production of the other product. This change in behaviour of the producers then decreased the price of the more attractive good again, therefore inducing an inverse relationship between prices for the two alternative food products.

42 An alternative specification of the regression for PROTEINS was tested by introducing also the winter temperature index into the equation. This direct winter temperature effect, which can be expected to be present because weather conditions during the winter were supposed to affect the lenght of pasture period during a year and therefore also to influence the price of proteins, turned out to be of positive sign *(0.019)* and was statistically not significant. In this regression the coefficient of determination R^2 *(0.816)* and the grain price effect *(-0.557)* remained virtually unchanged. Thus, this causal relationship was left out of the model.

43 $-0.133 \times -0.599 \times -0.137 = 0.011$.

44 $-0.133 \times -0.599 \times -0.309 \times -0.141 = 0.003$.

45 $0.009 + -0.002 + -0.011 + 0.003 = -0.001$.

stages of the 18th century could improve the biological standard of living significantly, but produced through richer harvests at the same time a considerable slowdown of this tremendous improvement because of the negative relationship between grain prices and prices for proteins.

Adding up the direct and all indirect effects, the total change in average height due to an one percent increase in winter weather conditions can be quantified as 0.017 percent *(Table 1)*. In the first half of the 18th century climatic conditions became significantly better during two subsequent phases: Firstly, from 1690–1699 to 1700–1709 the level of winter temperature rose by some 77 percent. Secondly, from 1730–1739 to 1740–1749 winter weather conditions improved again by about 70 percent. For the large increase of French average height in the first half of the 18th century this means that about 2.1 cm of the 5 cm (from 161 cm to 166 cm) gained at first were directly and indirectly due to this first escape from the Maunder Minimum. Thereafter, of the next significant improvement in average height from 164 cm to 168 cm almost 2 cm can be attributed to the second escape from the Maunder Minimum[46].

The effect of climate during the human growth process – a polynomial distributed lags model

For the estimation of age-specific effects of climate on height, a further simplified causal model is assumed which can be estimated using annual observations of height, temperatures and grain prices *(Figure 4)*[47]. Compared to the model described above

46 From 1690–1699 to 1700–1709 the average of the winter temperature index raised from -1.1666 (-0.704 °C) to -0.2666 (-0.115 °C) below the long-term mean, the improvement between decades 1730–39 and 1740–1749 was from -1/3 (-0.159 °C) to -0.1 (-0.006 °C). As seen above, a one-percent change in temperature provoked a 0.017-percent change in height. Given a reference height of 161 cm at the end of the 17th century, a 84-percent improvement of winter climate conditions transforms into an increase in height of 2.11 cm (*161 cm x 0.00017 x 77.1 = 2.11 cm*). For the second large improvement of winter climate the calculation is similar (*164 cm x 0.00017 x 70.0 = 1.95 cm*).

47 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 M. Mestayer, Les prix du blé et de l'avoine de 1329 à 1793, in: Revue du Nord 45 (1963) pp. 157–176, 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 has 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 of increases and decreases. The Douai grain price series is highly correlated with the Paris grain price series published by M. Baulant, Le prix des grains à Paris de 1431 à 1783, in: Annales. Économies. Sociétés. Civilisations 23 (1968) pp. 520–554, pp. 537–540 (for the period of 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 P. Goubert, Bauvais et le Beauvaisis de 1600 à 1730, 2 vols., Paris 1960). C. Bac, J.-M. Chevet, E. Ghysels, Time-series Model with Periodic Stochastic Regime Switching. Part II: Applications to 16th- and 17th-Century Grain Prices, in: Macroeconomic Dynamics 5 (2001) pp. 32–55, show market integration for several French grain markets in 16th and 17th centuries.

(Figure 3), in this case the measurement of climate is more refined. Climate now is a latent variable, measured in various dimensions. Therefore, additional indicators are taken into consideration: average temperatures (in England)[48], indices of summer temperature and the quantum of rainfall during autumn (in Switzerland)[49] and tree-ring growth (in the region of Burgundy)[50] are used to forecast the level of grain prices. Winter temperature is then used as the only proxy for weather condition that affected height directly.

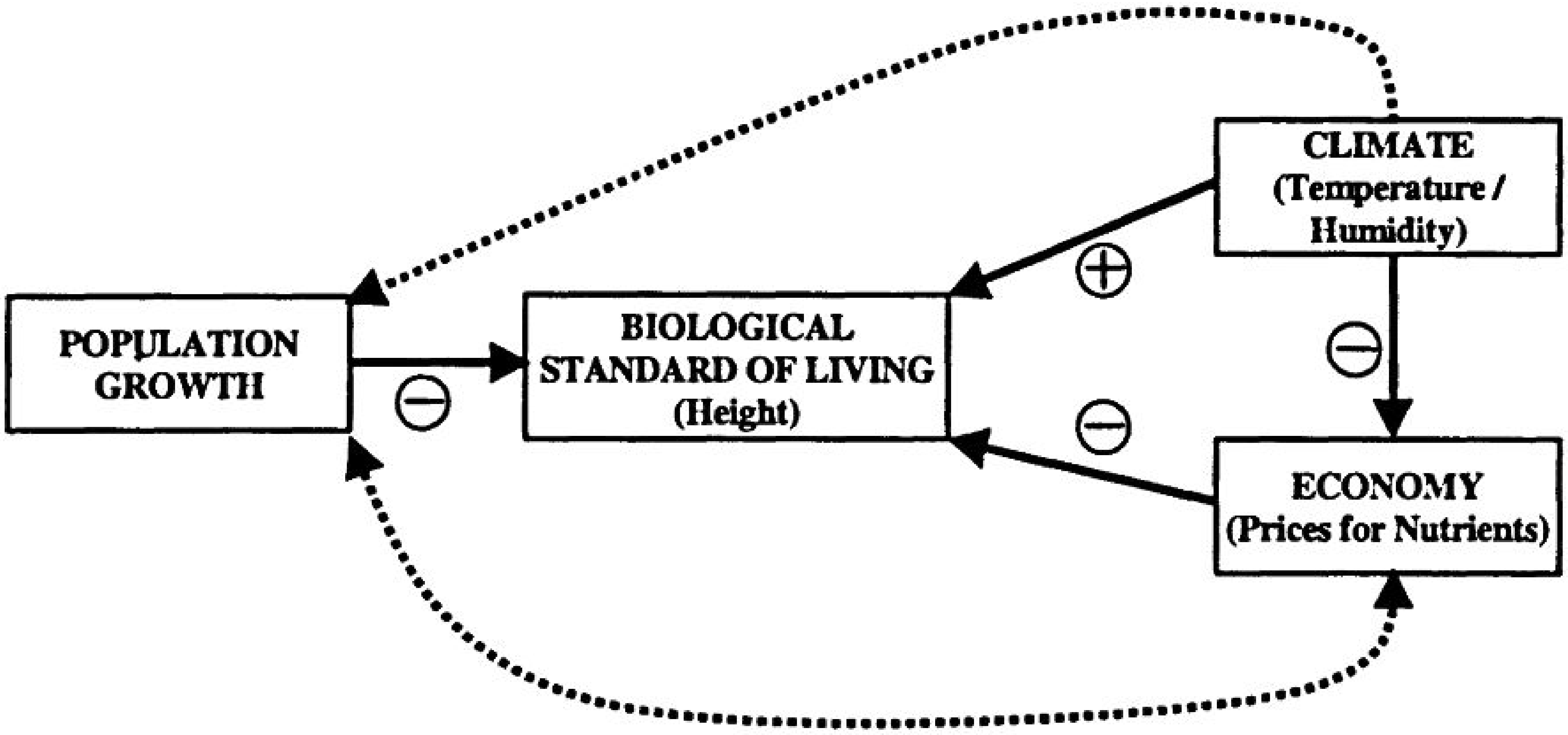


Figure 4: Causal diagram used to explain cohort-specific average height including hypotheses on the sign of effects.

48 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 J.-P. Legrand, M. LeGoff, Les observations météorologiques de Louis Morin, 2 vols., Paris 1992 (Direction de la Météorologie Nationale, Monographie No. 6) and C. Pfister, W. Bareiss, The Climate in Paris Between 1675 and 1715 According to the Meteorological Journal of Louis Morin, in: B. Frenzel, C. Pfister, B. Gläser (eds.), Climatic Trends and Anomalies in Europe 1675–1715, Stuttgart 1994, pp. 151–171 (Paleoklimaforschung, 13). 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 $r = 0.799$. The above cited Elisabeth Charlotte, Princess Palatine, possessed a thermometer and since she inserted weather-related observations into numerous of her letters, she seems to have measured temperature on a regular basis at the same time when Morin recorded his measurements. Cf. Voss (see note 25), p. 54.

49 The construction of these indices is exactly the same as is the construction of the index of winter temperatures (see note 31). The long-term average based on measurements in the period 1901–1960 is indicated with 0, deviation from this standard are scaled up to +3 (very hot summer, very wet fall) and down to -3 (very cold summer, very dry fall). Cf. Pfister (see note 14), p. 31. Christian Pfister provided the annual data.

50 D. de Vries, Burgundian Historical Climate Data, paper 2000 (23 pp.) [available under *www.unc.edu/depts/anthro/french/projects/climate/data_hist* ...]. See also D. S. Murray, An Introduction to the Historical Climatology of Burgundy, paper 2001 (7 pp.) [available under *www.unc.edu/depts/anthro/french/projects/climate/introduction* ...].

The specification of this 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 be able to still control for the effect of population growth, decennial population growth rates are split into annual growth rates assuming constant growth during a particular decade. Feed-back effects between the growth of population and the economy are excluded due to a small correlation coefficient[51] as is the causal influence of climate on population growth[52]. In relying on theoretical considerations and estimation results from the causal model discussed above, 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 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 had shown a higher average height than a birth cohort which grew up during more extreme conditions of climate. As it was with the more complex model for decennial averages of variables, the main purpose of this model is to decompose the overall impact of climate on annual average heights into direct and indirect effects.

To model the twofold impact of climate on physical stature, two equations are needed: 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)[53]:

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

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 and Swiss autumn rainfall and treering growth in the region of Burgundy:

$$(2) \quad p_t = \alpha_p \prod_{j=1}^{J} c_{jt}^{K_j}\, e^{v_t}$$

51 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 ($r = -0.042$).

52 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.

53 For an explanation of this assumption see J. Komlos, Nutrition and Economic Development in the Eighteenth-Century Habsburg Monarchy. An Anthropometric History, Princeton 1989, p. 29, and Komlos, Hau, Bourguinat (see note 8).

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)[54], the specification of the model allows the estimation of age-specific effects of climate on average height.

Effects of climate on grain prices

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)*[55] and, finally, a multiplicative model with the same set of regressor variabels as *Model Ib*, but assuming an U-shaped relationship between summer temperatures and grain prices instead of a linear one *(Model Ic)*[56]. As can

	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 2: Bivariate correlations (Pearson's r) between log values of climate indicators.

54 In anthropometrics this approach has been used for the analysis of lagged influences of GDP per capita on the prevalence of stunting in developing countries by H.-J. Brinkman, J. W. Drukker, B. Slot, Height and Income: A New Method for the Estimation of Historical National Income Series, in: Explorations in Economic History 25 (1988) pp. 227–264 and H.-J. Brinkman, J. W. Drukker, B. Slot, GDP per Capita and the Biological Standard of Living in Contemporary Developing Countries, Paper presented to the Pre-conference for the A-Session of the XII[th] International History Congress »The Biological Standard of Living and Economic Development: Anthropometric Measures, Nutrition, Health and Well-Being in Historical Perspective«, Munich 1997 (43 pp.).

55 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.

56 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

seen from the bivariate correlations depicted in *Table 2*, climate indicators are virtually uncorrelated.

Dependent variable:	**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 3: 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).

In general, as expected, a warmer and dryer climate reduced the price of grain, because harvest conditions were better[57]. The dryer the period of harvest, the lower were grain prices. In contrast to physiological considerations[58], 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

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).

57 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.

58 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 to the effect, that the following year's growth of grain is hampered as well. Cf. Baten (see note 13), p. 31. In addition to that, excess humidity in autumn hindered and delayed the sowing of springtime crops. Cf. PFISTER (see note 14), p. 35.

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.

Econometric specification of the model for height, estimation procedure and goodness of fit

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:

$$(3) \quad h_{t'} = \alpha_{ht'} \prod_{i=0}^{23} p_{t'-i}^{\beta_{pi}} \prod_{i=0}^{23} c_{t'-i}^{w\beta_{ci}} e^{ut'}$$

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 1666–1679 being the reference category[59]. 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 world 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.

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

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[60]. 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)[61].

At first, the level of average height of French adult men in the 17th and 18th centuries was influenced by changing levels of weather conditions during winter and by a changing grain price during the period of human growth[62]. Forecasted values of average height are highly correlated with the original data *(Figure 5)*. Furthermore, compared to the free parameter estimation of temperature and price effects on height the polynomial distributed lags specifications fit the data sufficiently well[63].

Concerning the effect of population growth on height, a slightly different result to that of the path model depicted in *Figure 3* appears. 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 only 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

60 See J. JOHNSTON, Econometric Methods, Singapore ³1984, pp. 352–358, on the econometrics of polynomial distributed lags model (Almon lag model). Whether these restrictions on the estimated regression coefficients are reasonable can be tested by comparing the performance of such a model to that of the free parameter estimation with a F-test.

61 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 more 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.

62 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-percent 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 different conditions of climate and different grain prices.

63 The polynomial distributed lags models have a higher adjusted $R^2_{adj.}$. See *Table 4* in the *Appendix*.

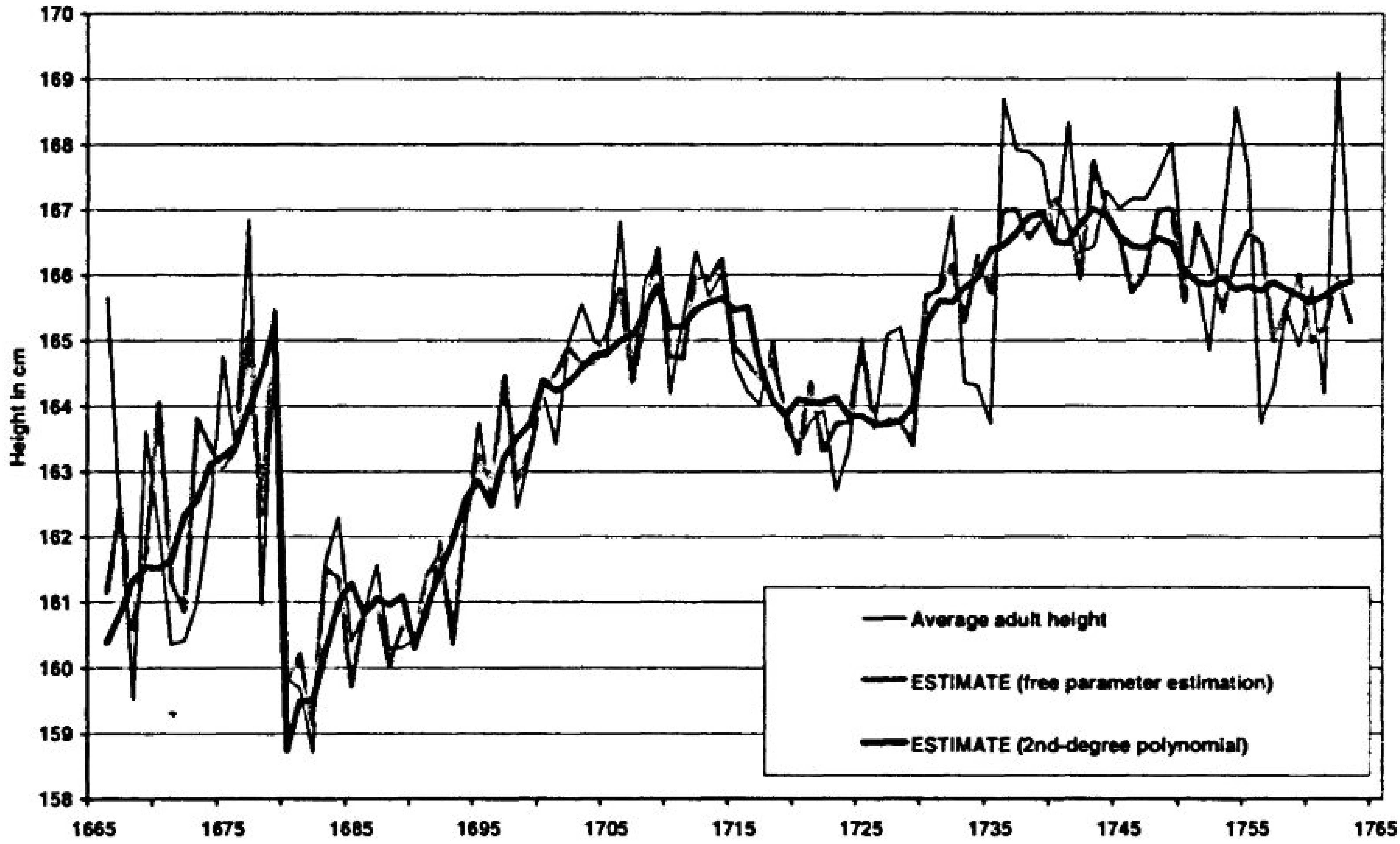


Figure 5: Development of average heights for birth cohorts 1666–1763 and heights forecasted on the basis of a model without any restrictions on effects of lagged grain prices and winter temperatures *(Model IIIb)* and with a second-degree polynomial distributed lags model *(Model IVb)*. Estimated values are correlated to original heights with $r = 0.890$ (free parameter estimation) and $r = 0.843$ (second-degree polynomial of lagged coefficients).

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 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.

Age-specific effects of winter temperatures and grain prices on height

In *Figures 6* and *7* the time structure of winter temperature and grain price effects on average height are depicted. As expected, the unrestricted estimation of effects yields

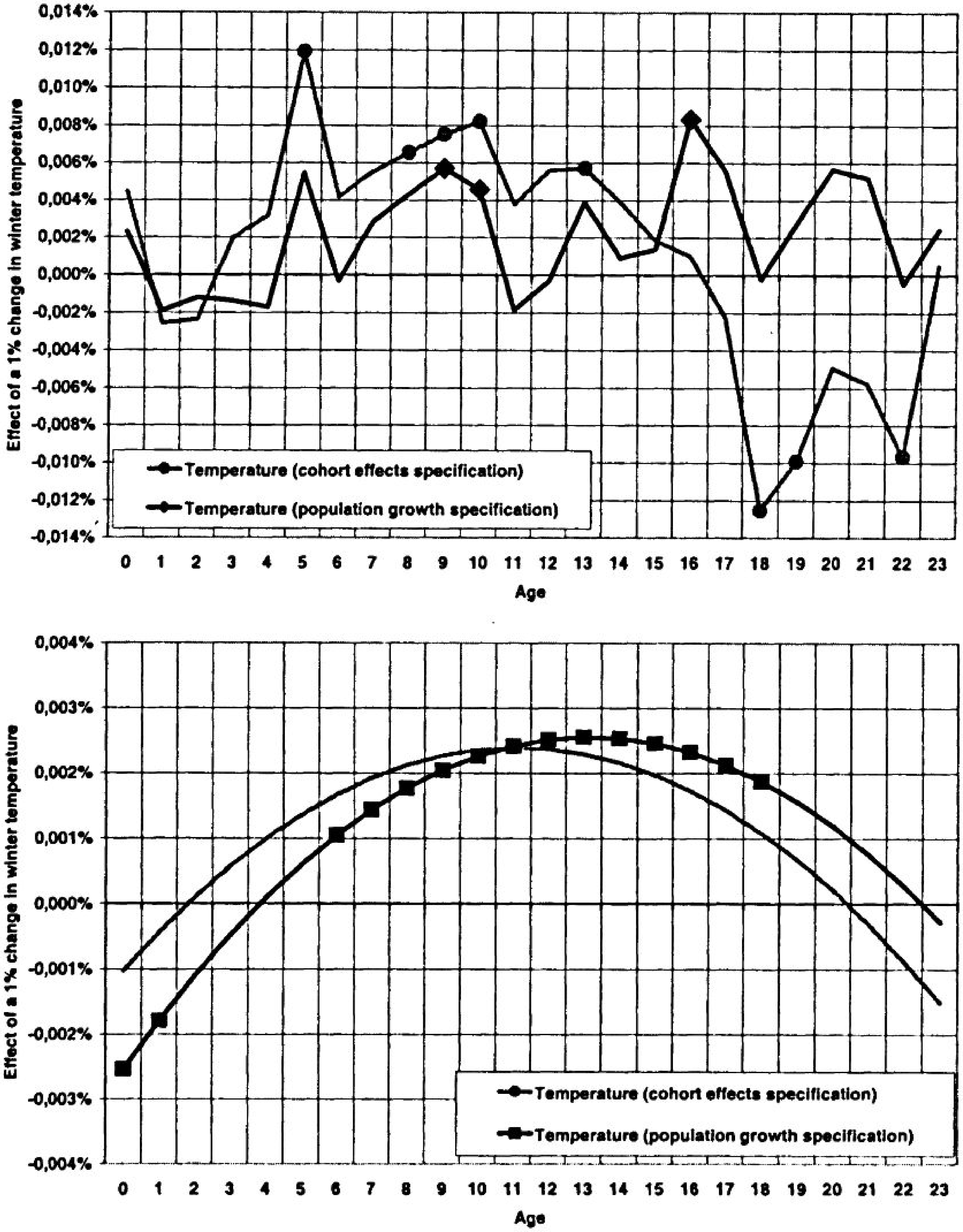
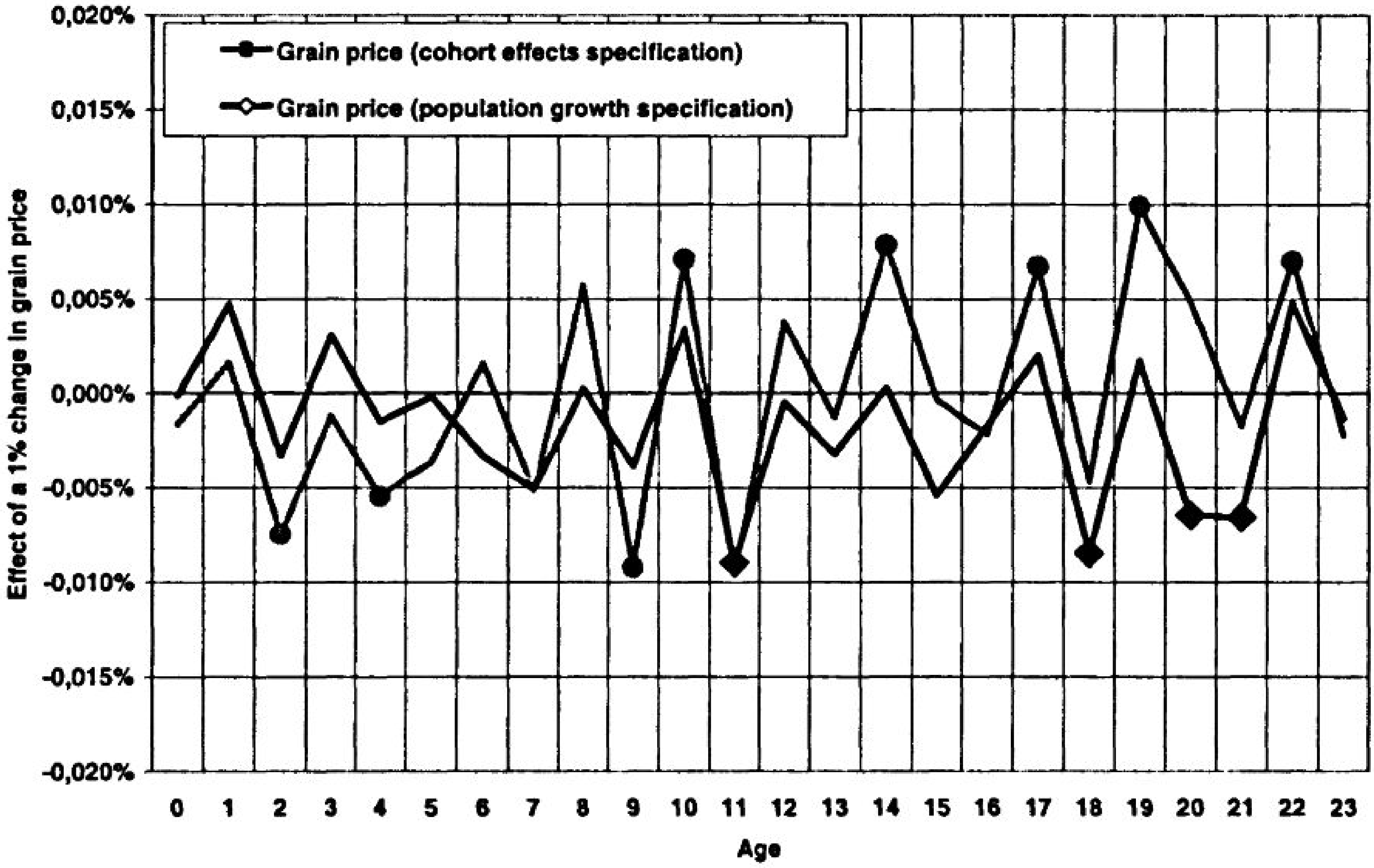


Figure 6: Age-specific effects of winter temperature on height for french birth cohorts 1666–1763 (elasticities). The lagged coefficients are estimated without restrictions and freely varying parameters (top) and with a second-degree polynomial (below). Both models are controlling for either cohort effects or population growth. Dots indicate effects that are significant at least at the 10%-level in a one-sided t-test.

mixed results with signs changing between ages (*Figure 6* and *7*, top panels). 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 both independent variables – index of winter temperature and grain price level – a second-degree polynomial is a quite sufficient representation of the effects' time structure (*Figure 6* and *7*, bottom panels)[64].

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 at ages 13–17, when an one-percent increase in the temperature index caused about 0.0025 percent increase in average height (*Figure 6*, 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. Moreover, the effects of grain prices were also most pronounced during the ages of 13–17. The higher were grain prices, the shorter was a cohort on average. Here again, during the very early childhood, a reverse sign is found. Hence, also for the grain price level one may conclude, that a selection mechanism due to unfavourable economic circumstances was in action, that tended to increase a cohort's final average height.

64 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.



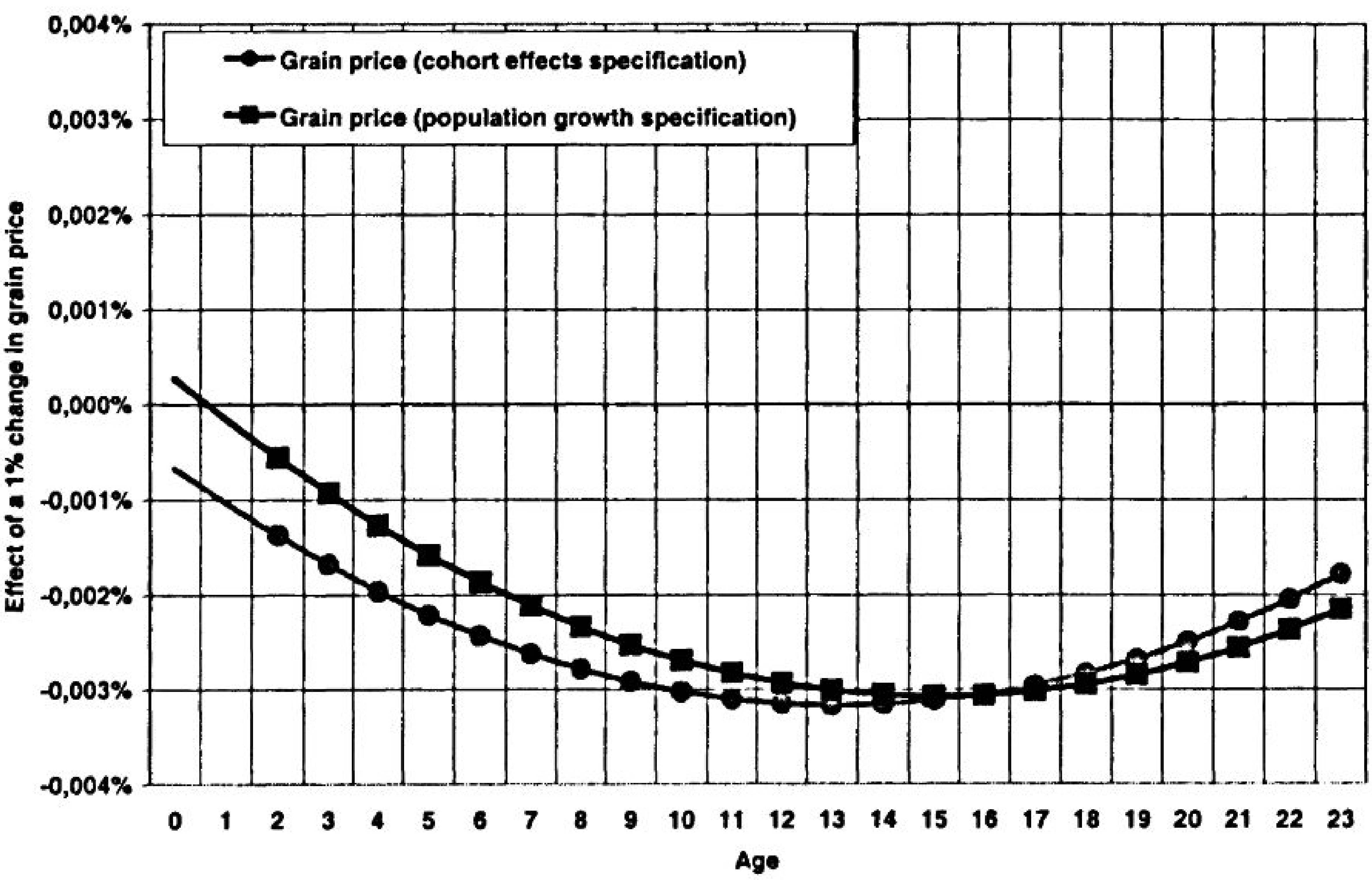


Figure 7: Effect of grainprice on height for french birth cohorts 1666–1763 (elasticities). The lagged coefficients are estimated without restrictions and freely varying parameters (top) and with a second-degree polynomial (below). Both models are controlling for either cohort effects or population growth. Dots indicate effects that are significant at least at the 10%-level in a one-sided t-test.

Decomposition of climatic effects on height

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 model. These compositional effects are calculated from the computations 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.

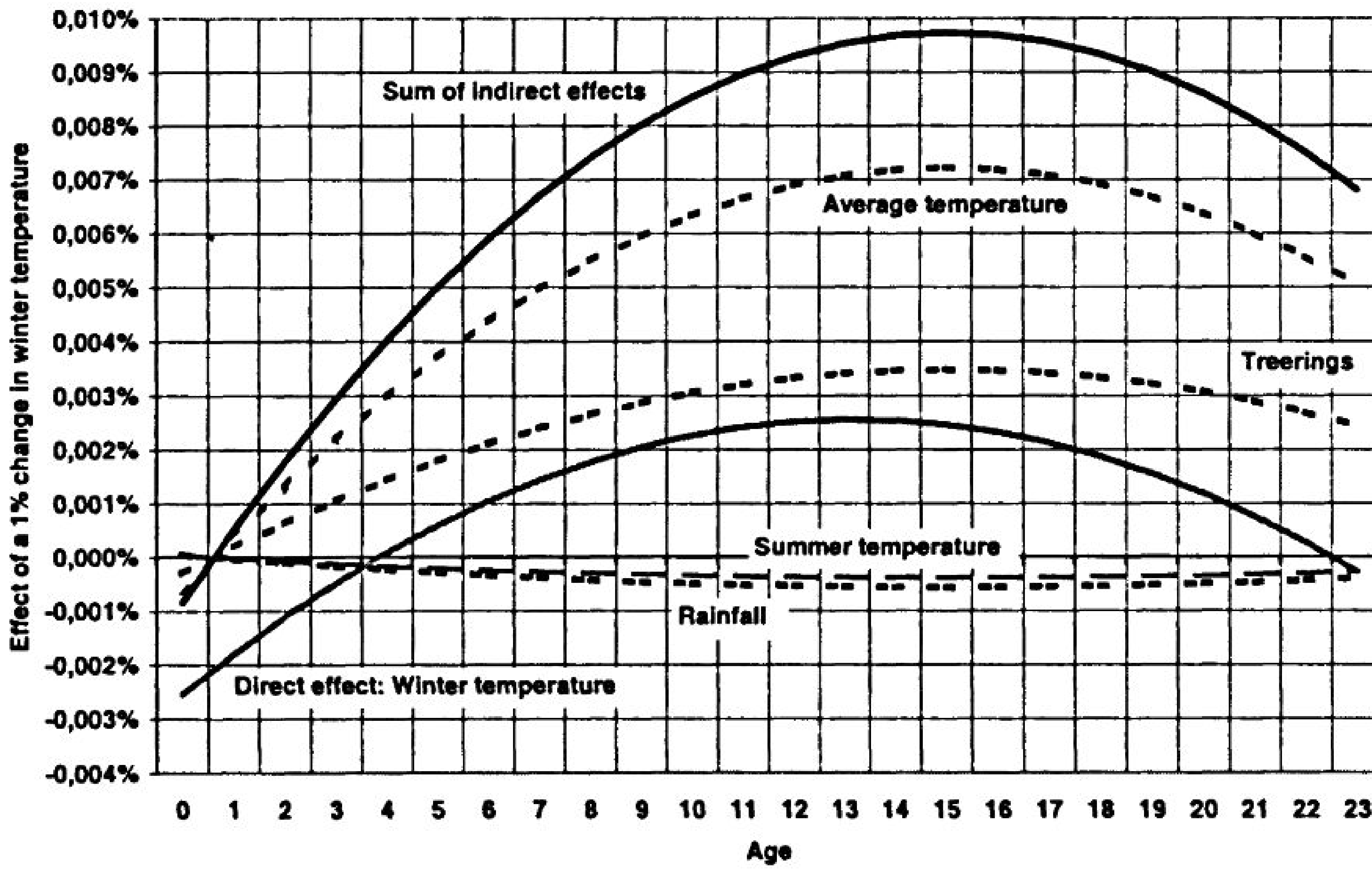


Figure 8: Decomposition of the total effect of climate on height for birth cohorts 1666–1763, using the estimations of age-specific elasticities of winter temperature index and grain price from the second-degree polynomial distributed lags model with population growth specification *(Model IVb)*. Indirect effects are calculated on the basis of *Model Ib*.

In *Figure 8* a decomposition of the total effect of climate is depicted. To calculate this decomposition, values for grain price effects are taken from the estimation of the second-degree polynomial distributed lags model that includes population growth parameters *(Model IVb)*. This 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)*[65]. The sum of all indirect effects peaks around

65 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 the decomposition described above.

ages 13–17, 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 1/4 of the overall impact on height[66]. 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.

Conclusions

In using a series of French adult heights for birth cohorts between 1666 and 1763, direct and indirect effects of climate on average height are estimated. Moreover, the age-specific magnitude of these effects during the growth process was estimated by applying a polynomial distributed lags model to the data. From the two different analyses – one on the basis of decennial averages, the other with annual data – the following conclusions can be drawn:

(a) Winter weather conditions had a pronounced overall effect on average height in Ancien Régime France. More than 50 percent of the subsequent shifts in average

66 This result does not contradict the finding obtained from the analysis of the more complex causal system using decennial averages of the data *(Figure 3)*, where it turned out that the aggregate indirect effect was of only marginal importance in comparison to the direct effect of winter temperature. Firstly, in the analysis of the annual data, climate is measured with multiple indicators. Therefore, the direct impact of winter temperature can be expected to be smaller, than if winter temperature was the only indicator. Secondly, the different indirect effects in the path analysis compensated each other because of the negative correlation between grain prices and prices of proteins. Since in the polynomial distributed lags model prices of nutrients are not incorporated, no indirect causal paths opposite to the interplay between indicators of climate and grain prices exist. Naturally, the aggregate indirect impact of climate then has to be of substantial order compared to only the direct effect of winter temperature.

height that occurred during the first half of the 18th century can be explained by the then significant improvement of climate.

(b) The improvement of climate affected French male heights not only indirectly via a more abundant food production, but also directly, presumably by providing people with better living conditions during the winter. 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 from 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.

(c) Age-specific effects of winter temperature and grain prices were largest during the early 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.

(d) On the basis of the simpler causal model used for the estimation of age-specific effects of climate on height, the total effect of climate can be aggregated from the direct effect of winter temperature and the indirect effects of other indicators of climate that are related to the level of grain prices. Although a compensation of both effects similar to that in the more complex path model cannot be found in this model, the presence of a profound direct effect of climate on height is supported by this model, too.

(e) Concerning the effect of population growth, the analysis reveals mixed results: On the basis of decennial averages for all variables, a clear negative effect of population growth on average height is estimated. In contrast, the estimated population growth rate effect on cohort-specific average height is significantly positive although rather minor in 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. Given these rather distinct results, 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.

(f) The period between c. 1660 and c. 1760 was characterised by an extreme and unfavourable climate, indeed. Especially temperaturewise it can be described as a »cold century«. 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 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 seen very clearly by decreases in the biological standard of living mainly among those cohorts that were born about 12–15 years before a crisis set off *(Figure 2)*. This result is in accordance with the parameter estimates of the polynomial distributed lags regression which suggest that the level effect of grain price on height was most pronounced in adolescence.

Appendix

Dependent variable:	**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	1.01530	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

to be continued on next page

Dependent variable:	**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 4: WLS parameter estimates for regressions of log heights. Significance levels for two-sided t-tests are denoted with *($p \leq 0.1$), **($p \leq 0.05$) and ***($p \leq 0.01$).