

# Climate, Grain Production and Nutritional Status in Southern Germany During the 18th Century

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## *Abstract*

What determined nutritional status in the 18th century? Long time series have been created on European climatic history in recent years, making it possible to compare these data sets with new estimates of nutritional status, grain production and real wages in Southern Germany. From the late 1720s to the late 1740s, winter temperatures in central Europe rose by 0.6 degree Celsius, and fell in subsequent decades by about 0.8 degree Celsius. Milder winter temperatures around mid-century influenced food production positively in Southern Germany. It kept pace with the growing population during this time period, and real wages did not decline up to the 1750s. Therefore, the development of nutritional status was positive. The cold winters after mid-century, however, had an extremely negative effect on food production, real wages, and nutritional status.

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## **Climate, Grain Production and Nutritional Status in Southern Germany During the 18th Century**

Was Malthus right in arguing that population growth tends to outpace the growth in supply? We know that technological progress freed Europe from the laws he proposed in the 19th century, but declining nutritional status in the late 18th century might validate his arguments for his own lifetime.<sup>2</sup> Wrigley and Schofield suggested that Malthus' hypothesis based on diminishing returns to labor ruled the English economy until 1800.<sup>3</sup> Komlos argued that declining trends of nutritional status after the middle of the 18th century were caused by population pressure which became so strong that the previously positive, 'Boserupian' effects of population growth gave way to Malthusian threats to the demographic system (table 1). This argument is strengthened by the fact that in North America of the 18th century, where land was abundantly available, such a Malthusian threat did not appear. In addition, densely populated areas such as Northern Bohemia or Lower Austria had a lower nutritional status, and lower average height, compared to Galicia or Hungary.<sup>4</sup>

If we think of subsistence crises in twentieth century less developed countries, two major influences come to mind: over-population (in relation to capital stock and resources) and climatic and natural catastrophes. Did climate also determine hunger and well-being in the European past? Long time series have been created on Central European climatic history in recent years, making it possible to compare these data sets with trends in nutritional status.<sup>5</sup> I explore the relationship between climatic conditions and physical stature and argue on the basis of the evidence that milder winters from the 1730s to the early 1750s influenced

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<sup>2</sup> T.R. Malthus (1798/1976); the contrary view in E. Boserup (1981).

<sup>3</sup> E.A. Wrigley and R.S. Schofield (1981).

<sup>4</sup> The relationship between height and nutritional status has been described so often that this paper omits a detailed characterisation of this method. See J.M. Tanner (1990); J. Komlos (1994a); R.W. Fogel (1984); T. Cuff (1995), p. 5; J. Komlos (1994b), p. 213/4;

<sup>5</sup> C. Pfister (1988), pp. 38-39; R. Glaser (1991).

nutritional status positively, while the cold winters between the late 1750s and early 1770s had a negative impact.<sup>6</sup>

In order to to broaden our knowledge of anthropometric history, trend estimates of heights in southern Germany during the 18th century are presented and compared to other European countries. I analyze 5882 measurements of soldiers born in the densely populated Southwest of Germany (Palatinate), and 15842 soldiers from the Southeast (Upper and Lower Bavaria and Upper Palatinate).<sup>7</sup> Climatically, the Palatinate in the Southwest was and is - much warmer than the southeastern regions. If the argument of the climatic impact on nutritional status is correct, one would expect better nutritional circumstances for the Palatinate in the late 18th century than for the other regions. Moreover, a favorable situation in the warm 1730s especially in cold Bavaria.

Height is a measure of net nutritional status; hence, changes in the disease environment and physical exertion may also have influenced this variable. A direct influence of climate on heights can also not be ruled out, for example, if colder winters demanded more calories to maintain body temperature. This effect is discussed in section 5. Nevertheless, I will argue in this paper that in 18th century southern Germany, food production influenced by climatic conditions was a more important factor in determining net nutritional status, even if the other variables (such as increased physical exertion) may have contributed to some degree.

### **1.1. The height data for Bavaria and the Palatinate**

The height data stem from military records of 1760-87 (called in the following "earlier sample") and 1805-11 ("later sample", see table 2). They were recorded by the armies of Bavaria and Palatinate, which were united in 1778.<sup>8</sup> For the period between 1787 and 1805, archival military records were found in the Bavarian War Archive, but the few scattered records did not yield sufficient number of measurements.<sup>9</sup> Because of this gap, the

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<sup>6</sup> I am assuming for this 18th century study that during a decline in the availability of food per capita, the intrahousehold distribution between children and adults remains either stable, or less resources are given to the

dependent children, and that the reverse is true for times of increasing availability of food. For similar considerations on the 19th century French parental consumption decisions, see D. Weir (1993).

<sup>7</sup> 'Upper and Lower Bavaria' will be called 'Bavaria' in the following. Other characteristics of the three regions are a very high milk per capita production in southern Bavaria, and low values for the Upper Palatinate and the Palatinate.

<sup>8</sup> Until 1778, the territory of Upper Palatinate was divided between Palatinate and Bavaria.

<sup>9</sup> Most of the lists were probably destroyed during the war. Only a few lists of Palatinate survive, but they were not representative enough for the territory under consideration. Later, Palatinate became part of the French Republic, and regions were structured differently from the time before and after the Napoleonic wars, see J. Kermann (year not given).

two samples will first be analyzed separately. The recruitment system in both armies was similar before unification. The troops consisted of about 50 percent volunteers and 50 percent draftees ('Landfahnen'), who were chosen by local authorities from the peasant and handicraft populations.<sup>7</sup> "Officers" were typically of upper class origin, while the ranks below them ("non-commissioned officers") were composed of a broad social mix, but predominantly of urban middle class background.

Up to 1788, recruitment rules contained the extremely high minimum height requirement of 167.7 cm for infantry, 170.2 cm for the elite groups, the so-called 'Leibsoldaten' and 'Grenadiers' in Palatinate, and 175.1 cm for Grenadiers in Bavaria.<sup>8</sup> Was this extremely high minimum height requirement actually applied? A method to answer this question is based on kernel density estimates that searches for the largest absolute slope of the smoothed height distribution.<sup>9</sup> This estimation technique showed that the extremely high minimum height requirement was not applied strictly. For adult infantry (23 to 50 years) the actual truncation point was estimated as 165.2 cm instead of 167.8 cm.

As the elite army categories were overrepresented in the data for earlier birth cohorts, dummy variables were assigned to avoid biases. The officers were taller because of their higher social origin, and so were the non-commissioned officers, medical and logistic personnel. The 1760-87 sample contains information on soldiers born between 1725 and 1769. The age structure by birth cohort in this sample consists especially of younger

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<sup>7</sup> See O. Bezzel (1925, 1930, 1933), esp. O. Bezzel (1930), p. 99.

<sup>8</sup> As the cavalry also had an upper height truncation and artillery selected their recruits by skill levels, this sample was restricted to the other three army categories.

<sup>9</sup> I am indebted to Markus Heintel for creating this procedure, documented in J. Baten and M. Heintel (1995), and Heintel (1996).

soldiers in the later birth cohorts, as a large fraction of the sample was recorded in the late 1770s and 1780s (figure 1). Consequently, virtually no soldiers aged 23-50 are in the birth cohort 1765-69. Therefore, the estimated trend in adult height must stop with the cohort born in the early 1760s. Only for the younger soldiers can the trend be extended until 1765-69.

The second sample was recorded during the Napoleonic wars. This later sample consists of 4596 soldiers from Bavaria; hence, its regional composition is comparable with only one of the three regions in the earlier sample. The selection process had radically changed compared to the earlier sample; after the recruitment laws of 1799 and 1805, the Bavarian army became a (restricted) draftee army. The minimum height requirement was relatively low (162.4 cm or 62 "Rhenanian Inch"), so few cases are missing on the left side of the height distribution among the birth cohorts of the 1770s and 1780s (figure 2). The impact of the recruitment systems during the two time periods on selection processes is discussed below, but first we examine the height trends.

## **1.2. Height Trends in Southern Germany, 1725-65**

In order to estimate trends and regional differences, two methods are used: Komlos & Kim method (K&K) and the 'Reduced sample maximum likelihood estimator' (RSMLE).<sup>10</sup> With the former method, the height distribution of every birth cohort is truncated at the highest minimum height requirement ever applied during the period under consideration. Then, the simple mean of the reduced sample is calculated, which is a constant function of the mean of the underlying 'true' distribution over time and across regions, assuming that the variance does not change dramatically. The advantage of the K&K method is its robustness against distortions of the sample distribution.<sup>11</sup> The second method enables regression of height on exogenous variables (for example, dummy variables

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<sup>10</sup> The K&K method was proposed by J. Komlos and J.H. Kim (1990); RSMLE was first applied to height studies by J. Trussell and K. Wachter (1984).

<sup>11</sup> In contrast, the previously often used Quantile Bend Estimators is very sensitive to small violations of the normality assumption, see J. Baten/M. Heintel (1995). <sup>15</sup> Ibid.

for age), but only yields reliable results if the truncation point is far enough below the mean.<sup>15</sup> A simulation study by Mokyr and O'Grada (1996) yielded favorable results even with the truncation was close to the mean, but this is not the case if significant rounding to the nearest inch or half inch is apparent. The Bavarian data of the earlier sample does not have much rounding. This is fortunate, because the truncation point is relatively close to the mean. The second sample does have substantial rounding, but the difference is more than an inch. Nevertheless, it is necessary to compare both estimators. Only if results estimated with both methods point in the same direction can a reliable height trend be confirmed.

In all three regions, the results of the RSMLE method show an upward trend between the birth cohorts of 1725-29 and 1750-54, and a downward trend thereafter (table 3, figure 3a). The region of Bavaria had the tallest soldiers during the 1730s, while in the last two birth cohorts soldiers from Palatinate rank at the top. The decline in Palatinate heights between 1750/54 and 1765/69 of about 1.4 cm is modest, compared to the decrease of Bavarian heights of 2.7 cm. Even if we take into account an error margin of 0.5 centimeter, the difference is considerable.<sup>12</sup> Excluding the elite army categories from estimation confirms the regional, ordinal differences (table 4).<sup>13</sup> The K&K method generally confirms these results; heights increased until mid-century and decreased thereafter (figure 3b to 3d). Because this method does not take covariates into account, the sample is divided into the two elite categories and the non-elite troops.<sup>14</sup> For the region of Bavaria, every birth cohort contains more than 30 individuals, even for the (on average) smallest army category of

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<sup>12</sup> On error margins, see *ibid*.

<sup>13</sup> "Ordinal", because the decline was strongest in Bavaria and weakest in Palatinate. One cannot expect the same centimeter estimates, as the selection process for the army categories was involved. For Upper Palatinate, the number of cases is too small to do this control estimation if the elite categories are excluded. The weighting of the army categories was done by their shares in the army (in Bavaria: 59% non-elite, 23% Leib, 18% Grenadiers, in Palatinate and Upper Palatinate: 68%, 16%, 16%). One might argue that the non-elite soldiers were more typical of the underlying population than the mixture of the three categories. In addition to estimating the non-elite soldiers separately, a simple sensitivity analysis was done, increasing the non-elite weights by 10%. This did not change the results to a visible extent.

<sup>14</sup> The number of cases for "Leibsoldaten" would be too small for some of the birth groups.

"Leibsoldaten". As we would expect from army regulations, the difference in height between elite and non-elite soldiers was greatest in Bavaria.<sup>15</sup>

### 1.3 Height Trends, 1770-94

The later sample of Bavarian recruits allows height estimates for the birth cohorts 1770-74 to 1790-94 (table 2 and 5).<sup>16</sup> The largest part of the height distribution lies above the minimum height requirement of 162.4 cm (figure 2). Heights were very low, especially in the first birth cohort. As the Bavarians experienced the largest subsistence crisis in 1771/72, this result is not particularly astonishing. In the following birth cohorts, heights recovered somewhat (figure 4a). K&K estimates confirm in the main the RSMLE estimates for the different army categories and age groups for which enough measurements are available (figures 4b and 4c). There was a bifurcation by army category. Only the non-elite soldiers' heights decreased temporarily - contrary to the main trend - between 1775/79 and 1780/84.<sup>17</sup>

To what extent can the two height series be compared? Height data from the military pose two especially serious problems: (1) the minimum height requirement which, as we discussed, is statistically manageable under certain circumstances and (2) the much more problematic selection biases (Mokyr/O'Grada 1996).<sup>18</sup> Changing the recruitment system from a volunteer to a draftee army can imply substantial selection biases, changes in labor market conditions can have an impact on the supply of "quality" recruits. Floud et al. (1982, 1990) and Komlos (1994a, p. 75-79) employed for their height estimates of 18th century England and Austria-Hungary not only military sources, but also data on boys who were measured in such institutions as the Marine Society and military schools. For Bavaria and

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<sup>15</sup> This height difference between elite and normal soldiers might be a military response of the extreme regional differences in nutritional status in Bavaria: In the mountainous region of Southern Bavaria, people were relatively tall because their supply of animal protein from milk was sufficient (see section below), in Northern Bavaria near the Danube river, nutritional status was much lower, see Baten (1998).

<sup>16</sup> In this case, the announced and the estimated minimum height requirement are identical (162.4 cm).

<sup>17</sup> Interestingly, their heights also decreased between 1765/69 and 1770/74. The earlier birth group was only included in the K&K estimate.

<sup>18</sup> See, for example, J. Mokyr and C. O'Grada's (1996) general critique of height analysis based on volunteer armies. Anthropologists have found that even the heights of the subpopulation "US basketball players" are normally distributed, so normality tests alone do not reject the hypothesis of selection bias.

the Palatinate, such a source has not yet been found, so both the changing selection process between the earlier and later sample and the Bavarian labor market deserve some attention.

As already mentioned, the earlier sample consists of approximately equal shares of volunteers and draftees ("Landfahnen"). The latter had typically lower class rural occupations, as the local communities selected them. These communities had an incentive to send the poorest of their group, as these were most at risk to require charity relief. On the other hand, as the Bavarian government controlled the selection process, the chosen recruits had to be tall and healthy enough to fulfill their military duties. In general, one would expect this part of the recruit population to have lower average net nutritional status than the underlying total population. The other half of the army, the volunteers, had obviously lower opportunity costs than inheriting sons of farmers, master craftsmen or other urban middle classes, as otherwise they would not have joined the army. Their alternative earning prospects must have been between those of the above mentioned middle class occupations and those of farm servants and day-laborers. The social groups one would expect in this segment are therefore simple craftsmen, landless peasants or non-inheriting sons of farmers. Within this group, no negative selection for heights is to be expected, as the volunteers were paid according to height. The recruitment officers used these means to get as healthy recruits as possible.

According to these considerations, in the earlier sample we have one half of the soldiers with neutral height selection, and the other half with probably negative selection. In contrast, the later sample was structured by different rules but had a similar outcome. After the recruitment reforms of 1799/1805, a restricted form of general service was introduced. A much larger part of the population was drafted, compared to the earlier sample. Excluded were the urban middle classes (which we find as non-commissioned officers in the army) and the first sons of farmers, if they were the only male descendants. The residual classes are again simple craftsmen, non-inheriting sons of farmers, and the rural and urban lower classes.

The social composition suggests that the two series for Bavaria can be compared. This is also plausible if one regards the height estimates of 1760-64, 1765-69 and 1770-74: the declining trend starting that started among the earlier sample continued until the famine



crisis birth cohort of 1770-74. An important argument against a significant role of the modified recruitment process is that the downward trend of heights that is found within the earlier sample, consisted of soldiers who were recruited entirely under the old system.

Was the decline in heights between 1750-54 and 1770-74 caused by labor market conditions? Following Mokyr and O'Grada's (1996) model, one would expect that falling real wages increase the willingness of the better nourished part of the population to join the army, as their opportunity costs would decrease. Real wages declined during this period due to climatic problems in food production, therefore this selection bias would have caused heights to increase, not to decline. Another biasing influence on the (partial) volunteer army of the earlier sample might be the incidence of war. During major wars, people who have the choice prefer not to volunteer for armies, and the recruitment officers pay higher wages and premia and accept lower "quality" recruits. However, Bavaria was not directly involved in military conflicts during 1760-87. In the Seven Years war, Bavaria was neutral, and the short war of Bavarian succession was fought between Prussia and Austria-Hungary.<sup>19</sup>

## **2. Comparing the Development of Heights with Real Wages, Grain- and Potato Production**

The original working hypothesis of anthropometric research consisted in a close connection between physical stature and conventional measures of the standard of living, such as, for example, real wages or real per capita income. In the course of the research it was shown that this connection was not always positive; in particular, the two variables were found to have drifted apart both in England and the USA between the 1820s and 1840s.<sup>20</sup> In the following section, the height-real wage relationship will be investigated for Bavaria in the 18th century. We deflate nominal wages by an index of rye prices insofar as a consumer

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<sup>19</sup> The Bavarian succession was only the cause of the war. In spite of not being directly involved in the conflicts, one could think of a war recruitment effect caused by the fear of war. Then one would expect a negative selection of the first birth groups, i.e. lower heights than 'normal', which would support the argument of this paper. A dummy variable for "recruitment 1760-63" cannot be included in the regressions, as this would lead to substantial multicollinearity with the time dummy "birth group 1730-34".

<sup>20</sup> J. Komlos (1997)

price index is not available for Bavaria. In addition, because of the imprecision of this method we will also correlate height with potato and grain production trends.

## **2.1 The Real Wages and Grain/Potato Production in Bavaria in the 18th Century**

The development of nominal wages in the 18th century, up to its very end, is marked by a far-reaching "monotony".<sup>21</sup> From about 1795 onwards - in an era marked by great wars - nominal wages rose until 1815, only to remain stuck again at a level that hardly changed until the early 1850s.<sup>22</sup> Thus, it was grain prices that largely determined the level of real wages, as the percentage of the worker's budget spent on bread was high, especially prior to the wide diffusion of the potato after 1770.<sup>27</sup> Therefore, the change in the real wage over time can best be approximated by dividing nominal wages by an index of rye prices.<sup>28</sup>

One would expect that a connection exists between rye-and-potato production and the real wages of the lower stratum. Rye production can be approximated by evaluating tithe lists.<sup>29</sup> Such tithe series have been compiled for two regions in Southern Germany.<sup>30</sup> Because tithe yields refer to a district, they are not per capita values. If the population in a district with a constant tithe yield grew, less rye per capita was thus produced. The tithe series, therefore, was deflated with the estimated average annual growth rate of the Bavarian population of 0.32%.<sup>31</sup> Because no estimates of the Bavarian population exists on an annual or even a decadal basis, this approximation must suffice for now.

This method of calculation shows a close relationship between real wages and grain production until the period 1770-74, that of the great hunger crisis. It was this crisis, historians of nutrition argue, that brought with it a breakthrough in the spread of the potato

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<sup>21</sup> H.-J. Gerhard (1984), p. 55.

<sup>22</sup> In North Germany as well, the wage rate hardly ever varied, aside from the era of the Seven Years' War (1756-63), in which nominal wages were somewhat higher. Cf. H.-J. Gerhard (1984a), p.56.

The increase in nominal wages in the period around 1800 appears to have differed greatly according to region. For Goettingen hod-carriers and apprentice bricklayers, nominal wages around 1815 were about 10% higher than around 1795; in Bremen, they rose by 40-50%. According to Elsas, apprentice bricklayers' wages in Munich rose by about 25%; according to Gerhard, they actually doubled. The latter data are, however, biased by the inclusion of different kinds of activities (e.g., workers of different skill levels). In figure 5, nominal wage increases after 1795 are based on Elsas's

calculations, which correspond to the mean for Goettingen and Bremen. Cf. H-J. Gerhard (1984): M. Elsas (1936), p. 733. It is true, we know little of the dynamics of unemployment, which averaged 40 to 50 days for construction artisans in the 18th century. In addition, there were at least 60 or 70 Sundays and feast days, cf. *ibid*.

<sup>27</sup> Here, Gerhard expresses reservation, based on a Hamburg household budget, which attributes greater weight to the cost of fuel. One can easily imagine that, in the largest metropolises of wood-poor north Germany, the relative price of wood was especially high. Cf. H-J. Gerhard (1984). On the significance of rye prices, cf. W. Abel (1966); T. Bengtsson (1995).

<sup>28</sup> On the basis of the following assumptions:

1. Over time, underemployment remained relatively constant. Therefore, changes in the nominal wage rate mirrored changes in the actual nominal wages.

2. The prices of other foodstuffs and for firewood are, on the basis of the substitution effect, correlated with the price of rye. Even if higher-valued foodstuffs (i.e., meat) showed a higher price elasticity of demand, the correlation of the index values was nonetheless high. Even wood production had opportunity costs: If rye rose in price, forests were more intensively cleared and drawn into food production, and labor inputs were reallocated; we know this from forest economists' discussion about the fear of a wood shortage in the 18th century.<sup>28</sup> Therefore, even the price of wood also tended to follow the price of rye.

3. The prices for other expenses (rent, clothing, other goods) changed so little, and their proportion of the total household budget in Bavaria was so small, that they did not substantially influence total living costs. Cf. also the section at the end.

<sup>29</sup> On the methodology and problems, cf. E. Le Roy Ladurie and J. Goy (1982), p. 24-26; C. Pfister (1988), p. 65-69. A connection of tithe yields, rye prices and winter temperatures is also shown by the research of W. Bauernfeind and U. Woitek (1996).

<sup>30</sup> Those regions are situated a few kilometers west of the later northwest boundary of Bavaria, thus exactly between (Upper/Lower) Bavaria, Upper Palatinate, and the Palatinate. I thank Ruediger Glaser, Wuerzburg, for these series, published in graphical form in R. Glaser (1991), p. 155. Because the territory of Wertheim was larger than that of Kuehlsheim, a weighted average, with the ratio 3:1, was calculated from both series. The two series move are highly correlated, the one of (colder!) Kuehlsheim is, however, somewhat more sensitive to climatic change.<sup>31</sup> Calculated from population estimates for 1700 and 1800 by M. Rauh (1996).

(figure 5).<sup>23</sup> Exactly the same chronology is found in the Swiss canton of Bern: After the diffusion of the potato, population began to grow more strongly than per capita grain production would permit.<sup>24</sup> This date represents a real revolution in the history of the potato in southern Germany: although the beginnings of its cultivation were already present, it was only then that the potato suddenly gained significance.<sup>25</sup> What quantitative contribution did potato production make after its broad diffusion? For Bavaria's northeastern neighbor, Saxony, the contribution of the potato to food production, compared with that of grain, can actually be quantified for a few sample years (table 6). According to these records, potato production made only a slight contribution to nutrition before 1772, even though it was cultivated occasionally by clergymen and large estate owners.<sup>26</sup> Only after the subsistence

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<sup>23</sup> H.J. Teuteberg/G. Wiegelmann (1986), p. 93-134; C.F.W. Dieterici (1838), p. 262.

<sup>24</sup> C. Pfister (1995), p. 177.

<sup>25</sup> M. Boehm (1995), p. 361, and the studies cited there.

<sup>26</sup> U. Schirmer (1996), p. 51.

crisis of 1771/72 did potatoes in Saxony become, as in Bavaria or Switzerland,<sup>27</sup> enormously popular.<sup>28</sup> We can compare the share of the potato output in food production in Saxony and Bavaria (in 1809/10, without Palatinate). In Bavaria, about 156 kg of rye, wheat, and spelt, versus 132 kg of potatoes were produced per capita.<sup>29</sup> The contribution of the potato was, therefore, about 17%, a similar magnitude as in Saxony (Saxony 1810: 22%). A decade earlier, the contribution of the potato in Bavaria has been estimated at 12%.<sup>30</sup> Therefore, the available information suggests that the chronology of potato cultivation in Bavaria was similar to that in Saxony, although the extent of cultivation was a quarter smaller (the difference between 17 and 22%). In view of contemporary reports on the sudden spread of the potato after the hunger experience of 1771/2, and the availability of comparative data for Saxony, we augment our tithe series for rye by the estimated potato output in Bavaria. We assume that the output was 2% of grain production between 1750 and 1770 and extrapolate this amount linearly until it reaches 12% in 1800 and 14% in 1810. The estimated series is closely correlated with real wages (figure 5). Only in the last five-year periods after 1795 was the real wage below the value that would have been expected from the production side.<sup>31</sup>

## 2.2 Comparison with the Estimated Development of Heights

Although a comparison of the two series with the trend of adult heights shows a general agreement, there are a few differences (figure 6).<sup>32</sup> Aside from the catastrophic

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<sup>27</sup> For Switzerland, two regional studies exist, dealing with the contribution of potato culture around 1760: one gives a share of 7% for all root crops (thus, inter alia, potatoes and turnips); the other considers the share of root crops too small to quantify. Cf. C. Pfister (1995), p. 191/192, who refers to the unpublished results of Frey and Stampfli.

<sup>28</sup> In the northern districts of what later became the Kingdom of Bavaria, substantially more potatoes were cultivated than in Saxony; in the southern regions, less, cf. Baten (1998), G. Angerpointer (1994). In the South, more labor and capital were probably invested in livestock raising and grain growing. Unfortunately there have been no studies of tithe yields for southern Bavaria; a less sharp decline in them would be expected, than in those regions that enthusiastically converted to potatoes.

<sup>29</sup> A weight unit of grain contains some 300% more calories than the same weight unit of potatoes, see C.F.W. Dieterici (1838); G. Angerpointer (1994).

<sup>30</sup> For 1800, Boehm estimates the contribution of grain to total calorie production at 67%, that of the potato at 9%, for a total of 76%. (This refers to total production, if only grain and potatoes are considered, the share of the potato is 12%). The remaining 24% of total calorie production consists of milk (19%) and meat (5%). Cf. M. Boehm (1995), p.91.

<sup>31</sup> Here one of the series could be inaccurate because of the influence of the war.

<sup>32</sup> According to our previous reasoning, the earlier and later height samples were spliced together.

harvests of 1740/41, wage and production values were, before the mid-eighteenth century, generally above average, while heights first rose, reaching their peak in 1750-54. Common to all three series is the decline from 1750-54 to 1770-74, during which heights fell by about 3 cm, far below the level of 1735-39. Grain production per capita diminished by about 20%; in the short term, real wages fell even more sharply. After 1770, heights in Bavaria recovered to some extent, as grain cultivation was supplemented in the densely populated regions by potato production. Real wages likewise recovered, because the price of rye, which caused their movement, was pressed downward by the new nutritional alternative of the potato.<sup>33</sup>

### **3. Climate and nutritional status**

The relationship between climate and food production is naturally complicated. Generally, climatic extremes are problematic for agriculture, both in terms of temperature and humidity. The monthly timing is very important; how warm and wet was it during the months of winter grain harvest, summer grain sowing and hay cutting? Threshold and interaction effects are also important, for example, if the temperature rose in May over 8° C and this was combined with late snowfall.

For the moment, we will construct a simplified model of the relationship between climate and agricultural production. First we consider the climatic determinants of animal protein production that played an often underestimated role in the nutritional experience of early modern societies. Winter temperature is specially related to this kind of agricultural production in Central, Eastern and Northern Europe.

Pfister has isolated four criteria that influenced the production of animal protein significantly in early modern Europe:<sup>34</sup>

1. How long did snow cover the pastures?

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<sup>33</sup> Unfortunately, a production series of milk and meat for Southern Germany cannot be estimated. W. Abel (1966) drew the conclusion from several investigations that Germans ate much less meat in the late 18th century than before. This can be supported by data from northern German regions on declining numbers of cows per capita, See my recalculations of W. Norden's (1984) results in Baten (1998).

<sup>34</sup> On the following, see C. Pfister (1988), pp. 38-39; R. Glaser (1991).

2. When did grass begin to grow in spring (meadows start to grow in spring when the temperature reaches 8° C), and when did it stop growing in autumn?

3. When was the grain harvest completed in autumn?

4. How humid was the hay cutting season in summer?

The duration of snow coverage - a product of both temperature and humidity - is decisive for the mortality of cows, because in favorable years the cows were removed from the stables already in March, and were quite healthy again during April and May. In bad years, however, the roughage for feeding the cattle did not last until the pastures were growing again in April or May. In these cases, the cows either perished or their milk production capacity was reduced.<sup>35</sup>

In Autumn, the cattle were brought to the stables as soon as temperature reached 5° C. As long as the cattle were outside, no roughage was needed, which could be kept for the winter. The last factor, the date of the grain harvest, is related to customs in early modern European agriculture; after the harvest, the village community was allowed to bring its cattle on the fields to graze. If the grain harvest was later than normal - typically caused by low temperatures in April to June - this advantage was reduced. These four variables influencing animal protein production (both dairy products and beef) tended to be negatively correlated with winter temperature. The colder the winters and the longer a period of cold winters, the more difficult it was to maintain the cattle stock. Obviously, a single hard winter (as in 1740) by itself after a year favorable for roughage production did not affect the cattle stock as seriously as a series of cold years.

The fourth influence on the amount and quality of hay (the most important roughage) was influenced by humidity in summer. If the summer was extremely rainy, the farmers had to wait with hay cutting for a dry period. If they waited too long, however, the hay had a low quality, because too much protein was used for plant growth. If it started raining after the hay was cut, the water washed out the nutrients. Fortunately for the parsimony of our model, winter temperature and humidity are correlated.<sup>36</sup> The residual of regressing

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<sup>35</sup> A Swiss peasant rule says: 'Hungered milk comes back, but frozen milk has vanished forever' ('Erhungerte Milch kommt wieder, erfrorene aber nicht mehr.') cited after C. Pfister (1988), pp. 38.

<sup>36</sup> R. Glaser (1991).

temperature on humidity must be left to the error term of the relationship between winter temperature and gross nutritional status for now.

Cold winters and short growing seasons also had a negative impact on grain harvests.<sup>37</sup> In addition, rye tended to develop mold poison in colder winters.<sup>47</sup> Grain production, however, was sensitive to many other factors: Humidity during the harvest (July/August) and sowing months for winter grain (September/October), drought, as well as hail. As the latter two factors were not correlated with winter temperatures, the amount of calories and vegetable protein available was not necessarily correlated with animal protein production. Thus substitution effects could buffer extreme cases of underproduction of either animal protein or grain.

In the history of nutrition, many sources are available on grain production, while animal protein and particularly milk production is poorly documented. Grain production was very important for urban populations, while meat was often regarded as 'luxury'. Milk, on the other hand, played an extremely important role in rural nutrition, but the amount produced was not recorded, because the peasants were not obliged to pay taxes on milk, and there was no other occasion when milk output could have been recorded.<sup>38</sup> Insofar as climate influenced milk and meat production, using climatic data might give us a clue to animal protein production of early modern Europe.

The connection between climate and food production has been investigated for an earlier period. Between the second and the last third of the sixteenth century, average spring temperature declined in Switzerland by 0.8° C, and average humidity in summer increased by 20 percentage points. Pfister has argued that milk production practically collapsed during this period. As the amount of roughage was reduced and the grazing season shortened, he estimated milk output to have been reduced by more than 50% (in the range of 55-193 million liters annually). For a population of 900,000 this meant a loss of 61 to 214 liters per capita. Grain production also declined by something between 10 and 33,000 thousand tons

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<sup>37</sup> In addition, one should not forget the manure provided by these animals, another decisive input for grain production.

<sup>47</sup> M.K. Matossian (1984); J. Komlos (1994a), p. 170.

<sup>38</sup> H.J. Teuteberg and G. Wiegmann (1986), p. 170.

(10 to 33kg per capita per year, about 10-15 percent of output).<sup>39</sup> Even if these margins of error are quite large, the effect of climatic deterioration on milk production appears to have been more dramatic than that of grain. For the 20th century (1901-1975), this relationship existed for hay yields and winter temperatures in Iceland.<sup>40</sup> The agricultures of Switzerland, Iceland and Southern Bavaria were probably affected particularly strong by climatic conditions due to their dependance on dairy products, but other European countries north of the Alps also suffered from deteriorating climate over a longer period of time. For example, Jan de Vries found a correlation between cold winters and rye prices in the Netherlands, and Patrick Galloway demonstrated the effects of temperatures on long run population growth, especially in the cold 14th and 17th centuries.<sup>51</sup>

What did the weather report look like in Malthus' time? As there are no temperature series for Bavaria before 1781, estimates for Switzerland serve as a proxy (figure 7). In general, winter temperatures were rising up to 1745-49, followed by a dramatic downturn until 1755-59. Winters remained cold until the temperatures recovered in the late 1780s. If one compares this time series with the estimates for food production, real wages and heights, time lags become important.<sup>41</sup> In favorable years, stocks of cattle and grain increased that enabled the population to maintain nutritional status through a series of adverse years. While the cattle stock was being reduced, additional protein (in meat) was made available for consumption. However, when climate became favorable again, it took some time to build up cattle stocks, especially in economies with low levels of interregional market integration. In the following analysis we assume that the average of winter temperatures in the current and the past five-year-period had an impact on nutritional status. This time-lag makes sense in terms of protein production, as cows typically live for five to ten years, and only about 12% live longer. The same is true for oxen, the main draught

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<sup>39</sup> C. Pfister (1988), pp. 84-95. On cattle in Austria, compare R. Sandgruber (1978).

<sup>40</sup> P. Bergthorsson (1985), pp. 113-123. Eckstein, Schultz and Wolpin (1982), p. 28, find a relationship between Swedish yields and winter temperatures 1756-1869, while autumn, summer and spring temperatures do not display this correlation. For excellent overviews of this topic, see P. Galloway (1986, 1994). <sup>51</sup> Jan de Vries (1980), p. 25; P. Galloway (1986), p. 7.

<sup>41</sup> Thanks to Robert Whaples for this important idea.



animal in southern Germany, an important item in the capital stock of the grain producing farmer.

The trend in winter temperatures and heights is similar (figure 8) The warm winters between the 1730s and the early 1750s (even with the exceptionally cold year of 1740) enabled Bavarian farmers to increase their cattle stock and grain production, while the cold years after mid-century had a negative impact on heights. The extremely cold year of 1771/72 that paralleled that famine crisis is not evident, as the surrounding years were relatively warm.

Thereafter, the relationship is less close. As noted above, the famine crisis promoted the spread of the potato. This technological innovation shifted the food supply, even if the temperatures rose only slowly. This reminds us of the possibilities to solve shortage problems that dampened the impact of climatic factors on the agricultural sector.

## **4 Country and Regional Comparison**

### **4.1. Comparison of the three regions in South Germany**

A further possibility for investigating the connection of climate and net nutritional status is offered by the varying climatic conditions in the three regions; sufficient anthropometric data for such a comparison exist in the earlier height sample. Of these regions, the Palatinate was the warmest and Bavaria the coldest.<sup>42</sup> Upper Palatinate<sup>43</sup> lay climatically between the two extremes. We would expect, therefore, that in the more climatically favorable era before mid-century, Bavaria would show the highest nutritional status, while this effect would be less marked in the somewhat warmer Palatinate. The trends of height actually does show this relationship (figure 3a). In the relatively warm period, men were taller in cooler Bavaria than in the warm, but densely settled, Palatinate. The reverse was true in the unfavorable phase after 1750-54: heights in cold Bavaria underwent a substantial decline, while the cooling of winter temperatures in the Palatinate did not have such a strong effect on heights. These varying reactions provide an indication of how significant the changes in climate was

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<sup>42</sup> Viebahn (1858).

<sup>43</sup> It included the Palatinate-Neuburg districts on the Danube.

on nutritional status, and how much stronger this effect was in colder regions than in warmer climates.

## 4.2 Comparison with Great Britain and Austria-Hungary

How do these trends in heights compare to other European countries? In brief, they are quite similar. The estimated trend for five regions of the Habsburg monarchy displays an upward trend in all five cases until the 1740s, and declining heights thereafter (figure 9a). For three regions in the United Kingdom, the downward trend after the middle of the 18th century is also visible (figure 9b), although it seems to have started later, especially in England.<sup>44</sup> There has been a debate about the British height trends, especially in the 18th century. Komlos' re-estimation of Floud et al.'s army data set display the same declining trend until 1800 as Floud and Wachter's estimates<sup>45</sup> of most age groups of Marine Society boys in London, and applying new kernel density modal estimation techniques on the latter data set yielded similar results for this time period.<sup>46</sup> In Sweden, heights increased until the 1740s and then declined until the 1780s, thereafter starting a recovery.<sup>47</sup> An especially strong increase in this cold northern country is visible in the warming period between the 1800s and the 1820s.<sup>59</sup>

While the continental climate in Austria-Hungary was similar to that of Switzerland and Bavaria, the maritime climate of the British isles was different. In England, the relative mild winters are reinforced by the effect of the Gulf Stream. January temperatures in central England from 1781 to 1850, were therefore about 4° C warmer than in Munich and 2° C warmer than in De Bilt in the Netherlands (figure 10). The variability of temperatures in England was also substantially smaller, as can be easily recognized by comparing maxima and minima. The warming trend until the 1730s, also favored better harvests in England and real wages clearly rose (figure 12).<sup>60</sup> When, after the 1730s, temperatures fell once again, real

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<sup>44</sup> J. Komlos (1993) recalculated the heights in the data set created by and described in R. Floud/K. Wachter/A. Gregory, A. (1990).

<sup>45</sup> R. Floud and K. Wachter (1982), p. 432.

<sup>46</sup> M. Heintel/J. Baten (1998).

<sup>47</sup> The new estimates in M. Heintel, L.G. Sandberg and R.H. Steckel (1998) are much more reliable than the older estimates in L.G. Sandberg and R.H. Steckel (1987), p. 104. For example the strange upward dip in the 1770s

wages began to fall, and continued with minor interruption until the turn of the century. Declining real wages also led to a decline in heights in 18th century England. In contrast to Southern Germany, English heights did not recover at the century's end, but fell again until the decade of 1800-09.

In summary, the following can be concluded with regard to England:

1. An influence of winter cold on real wages is evident, but it is much weaker than insouthern Germany or Austria-Hungary (figures 11a).<sup>61</sup>
2. There existed in England - for the seven decades after the 1740s for which data areavailable - a relatively close connection between real wages and heights (figure 11b).
3. A direct influence of climate on the decline in heights after the 1740s in England is farless obvious. The 1790s, especially, were relatively warm (figure 12); heights, however, nearly reached a nadir. The French wars probably contributed to low real wages around the turn of the century.<sup>62</sup>

completely disappeared in the RSMLE and K&K estimates of the Swedish volunteer data set, the trend looks extremely similar to the height trend in Southern German regions.

<sup>59</sup> M. Heintel, L.G. Sandberg and R.H. Steckel (1998)

<sup>60</sup> J. Komlos (1994a), p. 166-175. The temperatures for England are contemporary instrumental measurements from a single source and the temperature data on Switzerland are estimated by a much more comprehensive proxy approach, see Pfister (1988) for details.

<sup>61</sup> The residual in a regression (if the sample size of only 16 time periods were not so small) would be much larger. A certain influence can be found even if the extreme five-year period 1735-39 is excluded, as it is done in figure 11a.

<sup>62</sup> During Napoleon's Continental Blockade alternative transportation routes, e.g. across Archangelsk, made the grain supply more expensive.

Additional factors explaining the weak relationship between winter temperature and height come to mind. Within the climatic variable set, precipitation might have been more important than temperature. Another possible factor is the foreign trade in food. The foodstuff markets of the north European coastal countries were integrated by the 18th century.<sup>48</sup> After the climate had once more become unfavorable from the 1740s onward, England changed from foodstuff exporter to net importer. From the mid-18th century

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<sup>48</sup> B. Mironov (1985); J. Komlos (1994), p. 177. Food imports to England were small (1.4%) in relation to total food production in the 1770s and 1780s. Until the 1800s, they rose to 6.2%, Deane and Cole (1962), p. 65. The low estimates of the early decades do not mean that the imports were unimportant. Especially the large cities depended to much larger extent on food imports.

onwards, England paid its food imports with the income from her industrial exports. Because of favorable sea transportation possibilities, the country could be supplied with grain from the Baltic Sea area and with livestock products from Ireland.<sup>49</sup> In an investigation of the connection of climate and nutritional status in Great Britain, therefore, the climate in the Baltic area, as well as the climates of England and Ireland are important. We would expect that this would be reflected in English real wages, because when the climate worsened in grain-producing regions, the cost of living in England went up. Actually, data on the freezing of the Baltic Sea show that from the beginning of the 1750s to the turn of the century, the Baltic area was becoming cooler (figure 13).<sup>50</sup> The most extensive freezing of the Baltic Sea took place around 1800, when both heights and real wages in England reached their historic nadir. After the catastrophic 1790s and 1800s, the freezing of the Baltic decreased until the 1820s, and real wages and heights both recovered in England. If one includes for England not only the effect of domestic climate, but also the winter temperatures in the grain supplying countries, then a negative influence of winter cold on heights becomes evident even in the country that was the most industrially developed at the time.

## **5 Other factors influencing gross and net nutritional status**

Anthropometric studies have been criticised for focusing on the food intake variable in explaining trends in height in 18th and 19th century countries and regions.<sup>51</sup> Other factors such as disease environment or physical exertion of children might have also contributed to changes in heights.<sup>52</sup> These factors are more difficult to measure, and one has simultaneous equation effects, because worse nutrition increases the probability of the spread of many

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<sup>49</sup> It was similar for the Netherlands. Irish deliveries of foodstuffs to England are, on the contrary, not considered separately, because Ireland's climate was similar to that of England.

<sup>50</sup> The freezing index was calculated by Koslowski and Glaser (1995, p. 84/85) by arranging the data on ice volume from 13 coastal stations in an ordinal pattern of seven categories.

<sup>51</sup> M.E. Gregson and F. Grubb (1996).

<sup>52</sup> For a panel of French regions between 1840 and 1911, D. Weir (1993) found both a positive influence of real wages and a negative influence of mortality rates, standing for disease environment. In addition, the changes in intrahousehold distribution of resources between adults and children turned out to be very important, approximated by fertility rates. Attempts to prove the superior influence of the disease variable for the explanation of English height trends is problematic. H.-J. Voth and T. Leunig (1996) for example, selected only those three groups of boys that supported their argument and disregarded the eight other groups that did not support their contention, M. Heintel/J. Baten (1998).

diseases. Hence, we would need not only a morbidity indicator, but a variable already orthogonalized, removing the nutrition effect. As there is little hope to construct such an indicator, most studies use infant, child and overall mortality rates to proxy the disease environment. Is it possible that the disease environment worsened so much - independent of climatically induced food shortage - that the decline in heights between midcentury and the 1770s in south Germany can be explained by this factor? If we assume that mortality proxies the disease environment, the answer is probably not. Imhof found no obvious trend in life expectancy at age 0, 1, or 20 in Germany between 1740 and 1790<sup>53</sup>; between 1750 and 1770 there was a small increase in life expectancy at all ages.<sup>54</sup> Lee confirmed these results in his study of a few Bavarian villages (Hofmark Massenhausen) in the 18th century, finding that infant mortality until age one slightly declined between the 1750s and 1770s from 36.7 to 36.2 percent.<sup>56</sup> These numbers do not reflect short-term effects - for example, in the hunger crisis of 1771/72 mortality was much higher than normal - but in general, the available evidence suggests that the height trends in 18th century south Germany were not caused by nutrition-independent changes in the disease environment.

The second factor, physical exertion, is even more difficult to measure. Hans-Joachim Voth assumed that the abolition of several Catholic holidays in Austria-Hungary was a sign of increasing work load, including for children and young adults whose heights might have been reduced by exertion.<sup>57</sup> How many additional calories did it cost the already badly nourished children, to work in the fields or on the weaving looms during those extra days in the year? One possibility is that they would have worked less intensively, keeping the energy expenditures at a more or less constant level. Robert Fogel estimated that in France circa 1790, 20% of the population were not able to perform more than three hours of light work per day, and the inputs he used for this calculation were similar in Southern Germany and Austria-Hungary in the 1760s and 1770s. At that level of consumption, the

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<sup>53</sup> Thereafter it improved markedly until the climatically favorable 1820s.

<sup>54</sup> For males, remaining life expectancy improved between 1750 to 1770 (a) at age 0 from 35.7 to 38.0 (b) at age 1 from

<sup>55</sup> .8 to 46.3 (c) at age 20 from 36.3 to 40.2. See A. Imhof (1994), pp. 379-411.

<sup>56</sup> W.R. Lee (1979), p. 186.

<sup>57</sup> H.-J. Voth (1995, 1996). Komlos and Ritschl (1995), on the other hand, argue that this abolition of catholic holidays in Austria-Hungary cannot explain the decline of heights in 18th century protestant Sweden.

amount of calories spent on work must have been more strongly determined by the amount of calories consumed. At a time of good harvests and higher milk production the population was able to work more, and in a time with poor nourishment even governmental regulation would not make the workers in the fields, or their children, work more than physically possible. This view is supported by the fact that in the 19th century the length of the working day was longest in the 1860s and early 1870s, a time when the heights, real wages and food production were much higher than in the five earlier decades.<sup>58</sup>

A direct influence of climatic factors on the growth of children (independent of its effect on food production) cannot be ruled out, as the investigation of this issue would necessarily use the same variables as those in my climate - food production - height causal chain. Yet, direct climatic effects on physical stature is unsupported by the newer anthropological literature and cross-sectional evidence.<sup>59</sup> Holding the nutrient intake constant, people in northern Europe or in the Bavarian Alps would have been much shorter than people living in warmer areas according to this argument, but, this was certainly not true in the 18th or 19th centuries.<sup>60</sup> At the current stage of research, one cannot reject the hypothesis that the disease environment or physical exertion contributed to the cycles in height, but there is no evidence supporting their (independent) role for the 18th century.<sup>61</sup>

## 6 Conclusion

When Malthus published his essay on the principles of population in 1798, the relatively well-nourished Englishmen born in the 1730s were already 70 years old. Their younger contemporaries were considerably shorter in stature and less healthy, especially

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<sup>58</sup> To return to the disease factor, infant mortality also reached its long-term peak in German history during this period. See Baten (1998).

<sup>59</sup> See, for example, J.M. Tanner (1990), pp. 144-146, who only discusses very long-term effects of climate on bodyshape.

<sup>60</sup> On the other hand, one could imagine that the "tax" for diseases in colder areas would be lower, as many diseases spread faster in warmer temperature, and that this would offset the effect of cold climate in northern Europe or mountaneous areas. However, if this consideration would be true, it would also apply to explaining the development of heights over time.

<sup>61</sup> For the decline of British and US lower class heights between the 1820s and the 1840s, the disease factor might have played a role, but it was not independent of nutritional factors, more a reinforcement mechanism. Shifts towards a diet of less protein and more starches are also possible explanations, see J. Komlos (1987); R. Floud, K. Wachter, A. Gregory (1990), Baten (1998). <sup>76</sup> See Baten (1998).

those born in large towns and in densely populated areas. As the relationship between average height and nutritional status was known to some people of the 18th century, this decrease in heights might reinforced Malthus' pessimistic view of population growth.

I have argued that the deterioration in European climate beginning in the late 1750s contributed to the decline in nutritional status. Before this period, heights tended to be stable or increased in, and the climate was also favorable. I argued for a causal chain leading from warmer or colder winters to higher or lower grain and protein production, and these factors determined real wages and finally human stature, only slightly modified in central Europe by the new production technology of potato growing. In the cases of deviation from the trend as during the warm 1730s in otherwise cold and continental Bavaria - similar deviations existed in the height series.

Certainly, population growth reduced available food per capita (especially of animal protein) due to diminishing returns to labour, as Malthus asserted. In a regional cross-section of heights in Bavaria, one finds - similarly to the case of Austria-Hungary - that densely populated areas tended to have a lower net nutritional status.<sup>76</sup> Population growth was one of the two burdens in already densely populated Europe, taking into account the available stock of human and physical capital. Climatic conditions was the other.

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**Table 1: Population growth in the 18th Century**

Year:	around 1700	1750	1760	1770	1790	1800	Growth rate
England	5.1 1701	5.7 1751				8.6 1801	0,83 (1751-1801)
Ireland		3.2 1754			4.7 1791		1,04 (1754-1791)
Sweden		1.8 1750				2.3 1800	0,49 (1750-1800)
Germany (incl. Bavaria)		17.5 1750				22.0 1800	0,46 (1750-1800)
France.	19.7 1700		21.8 1762			27.3 1800	0,59 (1762-1800)
Bavaria	0.77 1700	0.90 1750				1.04* 1795	0,32 (1750-1795)
Upper Palat.	0.13 1700	0.18 1750				0.23 1795	0,55 (1750-1795)
Palatinate	0.16 1720			0.27 1772		0.34 1795	1,01 (1720-1795)
Lower Austria		0.93 1750			1.27 1789		0,68 (1750-1789)
Bohemia		1.97 1750			2.87 1790		0,95 (1750-1790)

\* including 'Innviertel', a territory that was lost in 1778.

Sources: England - Wrigley, E.A./Schofield, R.S. (1993); Ireland - Connell, K.H., *The Population of Ireland, 1750/1845*. Oxford 1950; France & Sweden - Mitchell, B.R.: *International Historical Statistics. Europe 1750-1988*. N.Y. Stockton Press 1992; Bavaria: Rauh, M. (1988); Austria - Komlos, J. (1994), p. 58; Germany - Pfister, C., *Bevölkerungsgeschichte und historische Demographie 1500-1800*. München 1994.

Region	Bavaria	Palat.	Upper Palatinate
early s.	1725-29	186	121
109			
1730-34	375	402	265
1735-39	570	575	379
1740-44	529	809	241
1745-49	673	600	383
1750-54	969	818	741
1755-59	984	934	935

1760-64	914	1000	1139	1765-
69	386	623	646	

later s. 1770-  
74 261

1775-79 844

1780-84 1676

1785-89 1166

1790-94 649

Source: Bayerisches Kriegsarchiv, Bestand AVI4d, (Musterungslisten).

**Table 3: Regression of heights using 'Reduced Sample Maximum Likelihood Estimation', all army categories (earlier sample, recruited 1760-87)**

Param.	Bavaria		Upper Palat.		Palatinate	
	p-val.	Param.	p-val.	Param.	p-val.	Param.
Const.	168.6	0.00	169.9	0.00	170.8	0.00
'Leibs.'	4.8	0.00	3.9	0.00	3.5	0.00
'Gren.'	8.0	0.00	6.7	0.00	5.7	0.00
Officer	2.5	0.00	3.9	0.00	4.4	0.00
NC.off.	1.5	0.00	2.4	0.00	1.5	0.00
birth yr	1725-29	-3.5	0.00	-4.3	0.00	-
	4.6	0.00				
	1730-34	-2.1	0.00	-3.4	0.00	-4.6
	1735-39	-1.3	0.00	-3.4	0.00	-3.9
	1740-44	-1.3	0.00	-1.8	0.00	-2.7
	1745-49	-0.7	0.00	-0.7	0.01	-1.1
	1755-59	-1.0	0.00	-0.3	0.27	-1.0
	1760-64	-1.9	0.00	-1.4	0.00	-1.1
	69	-2.7	0.00	-1.7	0.00	-1.4
						0.00
age 16		-3.1	0.04	-7.1	0.00	-8.9
						0.00
	17	-1.7	0.04	-5.2	0.00	-7.4
	18	-1.3	0.01	-3.2	0.00	-4.6
	19	-0.5	0.14	-1.2	0.00	-2.6
	20	-0.6	0.03	-1.1	0.00	-1.9
	21	-0.1	0.56	-0.4	0.01	-1.0
	22	-0.3	0.32	-0.7	0.00	-1.1
						0.00
						N
						5586
		5882		4838		

NC.Off = Non-commissioned officer

Source: Bayerisches Kriegsarchiv, Bestand AVI4d, (Musterungslisten).

The constant represents a non-elite soldier born 1750-54 aged 23-50

**Table 4: Regression of heights using RSMLE, elite soldiers excluded (earlier sample, recruited 1760-87)**

Param.	Bavaria		Palatinate	
	p	.Param.	p-val.	.Param.
Const.		165.2	0.00	170.3
				0.00
Officer		7.8	0.00	6.4
				0.00
NC.off.		6.2	0.00	3.4
				0.00

birth yr 1725-29	-5.0	0.00	-	
5.7	0.00			
1730-34	-4.0	0.00	-3.9	0.00
1735-39	-1.7	0.01	-3.7	0.00
1740-44	-2.6	0.00	-2.4	0.00
1745-49	-0.3	0.61	-1.6	0.00
1755-59	-0.4	0.41	-0.8	0.03
1760-64	-1.4	0.00	-0.5	0.17
1765-69	-3.2	0.00	-0.9	0.06
age 16	-2.8	0.28	-9.2	
0.00				
17	-3.1	0.00	-7.7	0.00
18	-2.0	0.03	-4.9	0.00
19	0.3	0.63	-2.7	0.00
20	-0.8	0.02	-2.0	0.00
21	0.1	0.68	-1.4	0.00
22	-1.1	0.11	-1.2	0.00

Source: see table 3

The constant represents a soldier born 1750-54 aged 23-50

**Table 5: Regression of heights using RSMLE, all army categories (later sample, recruited 1805-11)**

	Bavaria	
Param.	p-val.	
Const.	165.9	0.00
'Leibs.'	4.3	0.00
'Gren.'	6.7	0.00
Officer	3.4	0.00
NC.off .	3.4	0.00
birth yr 1770-74	-	
1.1	0.01	
1775-79	-0.3	0.29
1785-89	0.8	0.01
1790-95	1.0	0.01
age 16	-3.9	
0.01		
17	-2.3	0.00
18	-1.4	0.00
19	-1.5	0.00
20	-0.7	0.05
21	-0.1	0.86

22                    -0.1    0.86

N                    4596

NC.Off = Non-commissioned officer. Source: see table 3

The constant represents a non-elite soldier born 1780-84 aged 23-50.

**Table 6: Comparing the nutritional value (in calories) of potatoes to rye and wheat in Saxony**

	Rye	Wheat	Pop.	R.+W.	potato	potato
	in 1000 l	in 1000 l	in 1000	l p.c.	in 1000 l	share in %
1755	103792	9152	884,5	127	15080	3
1772	136240	21632	859,6	185	79976	13
1792	203840	30160	984,4	238	141232	15
1800	191256	37856	1027,5	223	168064	18
1810	202800	35880	1027,5	227	207584	22

Source: R. Gross (1968), pp. 54/55. Note: The nutritional value of a liter (abbreviated "l") unit potatoes (in calories) is 25% , see C.F.W. Dieterici (1838), p. 262