An Anthropometric History of early modern Europe with special consideration of the Holy Roman Empire, 1670 – 1760

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“Any form of knowledge has a chance of resonating with other kinds”

Gregory Benford – In the Ocean of Night

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Introduction

To some economists, nutritional status – measured for example by heights – suffers as a measure of living standards because height is not normally seen as something that can be bought." (Floud et. al. 2011, p.13). An individual with narrow-minded conceptualization of the economic profession may concur with this statement. However, once one delves deeper into the concepts and approaches used in anthropometrics, many connections between economic circumstances and biological indicators become evident, as well as instances where biological indicators help to uncover insights that traditional economic indicators cannot provide.

Thus, the primary topic of this dissertation in economics is the evolution of height in early-modern Europe. We provide a small building block to the already vast knowledge in anthropometrics[1], and our findings expand the established knowledge of the nutritional status of Europeans in the 17th and 18th century.

Adult height is the result of two main influences: The genetic potential and net nutrition (Steckel 1995, Deaton 2007). Silventoinen (2003), as well as McEvoy and Visscher (2009) both argued that 20% of the variation in stature can be attributed to environmental factors. Furthermore, Silventoinen (2003) stated that under environmental stress, the influence of the environment may even be higher. In addition, it is not likely that the observed short-term variation[2] in height is the results of genetic changes, since such short term changes in genetics are unlikely (McEvoy and Visscher 2009).
At the individual level, difference in height are the result of genetic influences (Bogin 2001). But, across populations, genes can explain less variation in mean heights than

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[1] The first sporadic attempts to study human height date back to the age of Enlightenment, but those studies suffered from imprecision (Steckel 2016a). Early examples are the Count of Montbeillard (Komlos 2003) and Leclerc de Buffon (Bogin 1999). A possible connection between economic circumstances and height was then investigated by Louis R. Villermé in the early 19th century (Kelly and Komlos 2016), Edouard Mallet studied the distribution of Genevan conscripts at the same time (Stab et al. 2011). His work is regarded as the first to discover the law of normal distribution by Staub et al. (2011) In the late 19th century, Francis Galton studied the relationship of parental and child heights, in search for a genetic rule behind the heritability of height (Cole 2000). The modern anthropometric history has its roots in the 1970s, and the field grew substantially after Fogel was awarded the Nobel Prize in economics in the 1990s (Kelly and Komlos 2016)

[2] Mc Evoy and Visscher (2009) made this statement with respect to the strong increase in mean stature in the last 150 years.

within populations (Deaton 2007), or as Steckel described it, *"[…] genetic differences approximately cancel in comparisons of averages across most populations […]"* (Steckel 1995, p.1903).

The concept of (net) nutritional status is used extensively in the literature (Steckel 1995, Komlos and Snowdon 2005, Floud et al. 2011) to model the influence of the environment on stature. An analogy by Richard Steckel illustrates basic principles behind the concept: Steckel describes the body as a "Biological Machine[3]" (Steckel 2009, 2016a). Food constitutes the body's fuel, and the body "burns" this fuel for various purposes. Part of the fuel is consumed to ensure vital functions like body temperature and blood circulation. If, for example, physical activities are performed or diseases need to be fought[4], more energy is needed. These body functions ensure survival and thus receive preferential weight if the body allocates energy. Thus, growth, which is also energy consuming (Floud et al. 2011), is suspended or decreases in velocity if not enough "fuel" is available to meet all demands (Steckel 2009). The concept of net nutritional status takes this "tradeoff[5]" into account. It *"[…] represents the energy which has been used for growth once the demands of body maintenance, resistance to disease, play, and work have been satisfied"* (Floud et al. 2011, p.11). Because the growth process of a human being stretches over several years (see Bogin 1999, figure 2.5, p.69,), *"height at a particular age reflects and individual's history of net nutrition"* (Steckel 1995, p.1910).

A number of environmental factors influence human height[6], We mention a two factors here where the connection to economics is evident: The composition of the diet, (Komlos 1998, Grasgruber et al. 2016) the caloric intake (Fogel 2004, Floud et al 2011). The caloric intake is a function of individual or family income and food prices, and the composition of the diet is influenced, ceteris paribus, by the relative prices of different types[7] of nutrients (Komlos 1998).

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[3] The most extreme version of such a concept was formulated by the French philosopher Julien Offray de la Mettrie in "L'homme machine" (1748) where he considers the entire human being as a machine.

[4] Raising body temperature consumes energy, as well as the immune system. If a disease affects the body's ability to fully digest food, the nutrient intake may also suffer (Steckel 2009).

[5] Komlos formulated this principle in a different manner: He stated that "[…] the first law of thermodynamics holds for humans, as it does for all plants and animals" (Komlos and Snowdon 2005, p.104).

[6] For a detailed review, see Steckel (1995, 2009). It is beyond the scope of an introduction to discuss all determinants of stature.

[7] Carbohydrates and protein.

Height offers a number of advantages, compared to conventional economic indicators: Firstly, height can easily be measured and observed, (McEvoy and Visscher 2009), while health, for example, is difficult to measure (Komlos and Snowdon 2005).

Secondly, the nutritional status is an indicator that is available for epochs where traditional economic measures, such as GNP or GDP do not exist or are scarce (Steckel 1995, 2016a). For example, real wage estimates for Europe or specific nations are exclusively based on prices from an often small set of cities[8]. (Van Zanden 1999, Allen 2001, Pfister 2017).

Thirdly, height is useful to study the well-being of populations that do not engage in market activity (Steckel 2016b). The height by age profile of American slaves is an illustrative example. Young children of slaves tended to be extremely short, but during adolescence, they experienced a phase of catch-up growth that ultimately led to an adult height comparable to that of upper class Europeans (Steckel 2009). Furthermore, such a growth profile is not found among malnourished populations today (Steckel 2016b). This finding is remarkable in itself, but more strikingly, one can derive that the growth pattern of slaves could have been the result of an investment[9] decision by the slave owners (Steckel 2016b). A higher quality diet that contained meat was only profitable once a slave child entered the labor force (Steckel 2016b). This offers an example where research based on height sheds a light on mechanisms of exploitation from an angle that conventional economic indicators cannot capture.

Fourthly, the analysis of anthropometric indicators can supplement[10] the conclusions drawn based on conventional economic indicators (Baten and Komlos 1998). As examples, consider the development of the nutritional status in the Antebellum (1830-1860) United States, a period when per capita output was increasing, but the nutritional status deteriorated[11] (Komlos 1987). Heights also decreased in England with the onset of the Industrial and Demographic Revolution in the 1760s, (Komlos and Küchenhoff 2012).

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[8] For the time period studied in this dissertation, this does also apply to other indicators of biological well-being, such as mortality. If data exists at all for the 18th, let alone the 17th century, the data are often confined to individual parishes (see for example Imhof 1994).

[9] For a theoretical model of food allocation in a slave economy, see (Rees et al. 2003).

[10] Because the nutritional status also captures aspects of well-being that are not reflected in conventional indicators (Komlos and Snowdon 2005), the term "biological standard of living" is also used in the literature. Throughout this dissertation, the terms "biological standard of living and (net) nutritional status are used interchangeably, as in Cinnirella (2008).

[11] The reason for this decline was an agricultural development that could not match the demands of a growing population, as well as increased market integration (Komlos 1987).

Finally, height is also one of many[12] biological indicators of well-being[13], and, because nutrition and health are "fundamental aspects of living standards" (Koepke 2016, p.70), height is also useful as an indicator of the standard of living. Height is also a predictor of health and socio-economic outcomes (McEvoy and Visscher 2009).

The usefulness of heights as a measure of well-being can be summarized: *"[…] we can use the average height of any group of people as a barometer of the health of their society"* (Bogin 2001, p.235).

Three chapters of this dissertation are based on data that was previously un-researched. A large number of muster rolls of foreign regiments of the French army were digitized. These rolls document the voluntary enlistment of individuals born throughout Europe on a yearly basis. Most enlistees were born in central Europe (modern day France and Germany), but the data also contain Irish, Italian and Swiss recruits. We are extremely grateful to John Komlos for granting us the opportunity to analyze this amazing dataset[14]. The data contains height data for individuals who were measured while still alive. This offers distinctive advantages over the study of skeletal remains (e.g. Steckel 2004, Koepke and Baten 2005, Koepke 2016), from which inferences[15] on the stature are also feasible. Military records pertain to men, but for skeletal remains to be useful, the pelvis must be among the discovered remains, because the correlation of height and bone length is sex-specific (Koepke 2016). Furthermore, skeletal remains do not allow the study of short term variations in stature, since *"In general, a better temporal resolution than one century is beyond the means of the archaeological evidence"* (Koepke 2016, p.73). Short-term fluctuations and cycles in stature are common, however. Woitek (2003) identified cycles in stature with a length that spans between 3 and 10 years of birth. These correlate with economic conditions and are therefore of interest. Such cycles are "smoothed out" when skeletal remains are studied. Thus, throughout the dissertation, we do not take research about skeletal remains into account when we put our results into context[16].

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[12] In Steckel's (2016a) overview, among physical height, life expectancy at birth, morbidity, and skeletal remains are discussed.

[13] Well-being may encompass material as well as psychological health (Steckel 2016a).

[14] Financial support of the DFG in acquiring and digitizing the muster rolls is also acknowledged (DFG Projekt KO 1449/17-1).

[15] Using the length of the femur (Koepke 2016).

[16] This does not imply that we dismiss the findings of research on skeletal remains, but that we consider it beyond the scope of this dissertation to incorporate the findings.

This dissertation in composed of three separate papers, in four chapters.

Chapters 1 and 2 are the core of this dissertation, and they constitute a single paper. Chapters 3 and 4 each constitute individual self-contained papers.

In chapter 1, we analyzed the nutritional status in the Holy Roman Empire from the second half of the 17th to middle of the 18th century. Our findings are the first estimates of trends in physical stature pertaining to inhabitants of the entire Holy Roman Empire before the 1730s.

We found that heights increased from the late 17th century to the first decade of the 18th century. Subsequently, a decline in stature ensued that lasted into the 1730s. Heights recovered again and attained a level that was previously unseen in the 17th and 18th centuries. The recovery was short lived, the nutritional status worsened considerably in the 1750s and 1760s. In this last aspect, our findings align with the established knowledge on the nutritional status of other European populations.

Region-specific estimates of the nutritional status are in general highly correlated, but in terms of the levels of heights, we could document a divergence. While the nutritional status was largely similar in all regions of the Empire in the first decade of the 18th century, (the largest difference in heights being 1.4 cm), this difference increased to a maximum of 8 cm in 1760.

In chapter 2, we extensively discuss the most likely determinants of the variations in the nutritional status we documented in chapter 1. We pursued different approaches, from simple correlations to multivariate and truncated regression analysis to uncover possible relationships between heights and a set of determinants. Due to very limited data availability, we primarily considered grain prices as having explanatory power, as bread consumed a large share of a worker's budget (Van Zanden 1999) and grain prices reflect agricultural conditions (Komlos 2003). In addition to grain prices, we also considered climate data, as they influence harvests and also reflect general environmental conditions (Komlos 2003). The influences of real wages and total population were also discussed.

We found that agricultural and environmental conditions can contribute to the explanation of our trend estimates, but the strength of the relationship was not constant over time. Real wages and population can also contribute, but not in every space of time studied. The worsening of the nutritional status in the second half of the 18th century is consistent with reports of growing population pressure, combined with decreasing marginal productivity of agriculture, as the amount of arable land necessary to feed the growing population could not expand rapidly enough. We essentially support Komlos' (1993, 1998) and Koch's (2012) argument that the decline in stature was the sign of a Malthusian crisis. We also examined population density as a plausible cause for the cross-sectional variation in height, but the picture of a generally negative relationship between height and population density is obscured by some outliers.

Chapter 3 is a paper on secular trends in height in the 17th and 18th century for other European nations. In this chapter, we make two contributions: Firstly, we extend the knowledge about the European nutritional status, in particular for some previously un-researched countries or regions. Secondly, we explore whether these populations were susceptible to fluctuations in grain prices. We found substantial differences in estimated height, as well as differences in the susceptibility to grain price fluctuations.

Chapter 4 deviates from the previous chapters. We did not analyze data on height, but we explored the properties of A'Hearn's (2004) restricted truncated normal regression estimator, an estimator that has been predominantly used in applied anthropometrics. A'Hearn (2004) established that this estimator can be superior in term of its Mean Squared Error to the conventional truncated normal regression estimator when estimating a constant. Due to the non-linearity of the estimation method used in the restricted as well as unrestricted truncated regressions, our analysis is based on an extensive set of Monte Carlo simulations as was A'Hearn's (2004) paper, but we complemented his work in three aspects: Firstly, we used a different criterion to compare the restricted and unrestricted versions of the estimator. Our criterion takes one additional parameter into account when comparing estimators. Secondly, we formalized the method by which we calculate the parameter combinations where the restricted estimator is superior. Finally, we extended the simulation to a model that contains a random variable as regressor.

We found that the superiority of the restricted estimator in certain situations is preserved when using our criterion, and also in situations where a regressor in contained in the model.

We intended each of the three papers to be self-contained, and thus, in particular in the introductory sections and in the discussions of the econometric methods, re-iterations of aspects discussed in previous chapters are unavoidable. Readers familiar with the respective topics are encouraged to skip the respective sections.

An over-arching theme of this dissertation is not only the focus on anthropometrics, but also the use of established smoothing techniques that allow the estimation of a relationship between variables without assuming a specific functional form. This flexible modelling of relationships among variables is even present in chapter 4, where we used certain properties of the flexible functions to calculate and visualize our results.

This dissertation also contains an appendix to the first paper (chapters 1 and 2), where we present a number of robustness checks and supplementary regressions. Some definitions of concepts used in the main text can also be found there. The appendix is not a prerequisite to understand the results in the main text and is intended for readers interested in a very specific aspect of the analysis.

Since we are the first researchers working with this newly digitized dataset, the dissertation also contains a data appendix, which is a detailed description of our data re-coding. The data appendix is not a prerequisite to understand the results presented in chapters 1, 2, 3 and 4, but is included to allow for a complete picture of the data that has been digitized. Furthermore, it is intended as a reference and code-book for researchers who wish to work with the dataset.

Numbers of tables, figures and footnotes are consecutively numbered in chapters 1 and 2 In chapters 3, 4 as well as in both appendices, all respective numbers start again at 1 in each chapter and appendix.

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Chapter 1:

1. The nutritional status in the Holy Roman Empire, ca.1670 to 1760

Anthropometric research has made considerable advances since the inception of the "new anthropometric history" (Steckel 1998, 2009) some 40 years ago. Richard H. Steckel summarized the initial reaction of the scientific community towards anthropometric research: *"[...] papers often rejected by journals on the heels of comments by wary and puzzled referees"* (Steckel 1998, p.804). But at present, anthropometric results have gained a reputation as a well-established indicator of human welfare (Steckel 2009). This valuation is shared by Floud et al. (2011), who consider the physical growth as a common indicator of the nutritional status of a population[1], and Allen and his co-authors, who regard height as one of the *"central dimensions"* (Allen et al. 2005, p.13) of well-being[2].

Researchers could establish stature as a coequal indicator of the standard of living for it offers distinctive advantages over other, more conventional indicators of living standards: For example, GNP estimates are either unreliable or non-existent in some historical contexts (Steckel 1995). Moreover, even if GNP estimates are available, they do not necessarily reflect the distribution of income, as stature is not only a function of the level of income, but it is also a function of the income distribution (Steckel 1995). In addition, height can reflect aspects of well-being that are not easily measured directly, whereas stature can serve as a proxy for health and well-being in general: For example, Komlos and Snowdon (2005) argue that health is difficult to measure, while stature is not. Anthropometric studies can uncover what Komlos calls *"hidden costs of economic development"* (Komlos 1987, p.921): Despite a growth in the output per capita, the nutritional status of a population may deteriorate. Komlos and Snowdon (2005) indicate another advantage of using stature as an indicator of well-being: Height is an outcome-measure, while income is not.

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[1] Such inferences are feasible because only the variation in height between individuals is explained by genetic differences (Bogin 2001), and these differences nullify each other when averages in stature across populations are analyzed (Steckel 1995, Bogin 2001).

[2] The other being weight.

Height at a given age is a function of an individual's net nutrition (Steckel 1995), and adult stature summarizes the history of the net nutritional status of an individual (Komlos and Snowdon 2005). Net nutrition is defined as *"[…] the energy which has been used for growth once the demands of body maintenance, resistance to disease, play, and work have been satisfied"* (Floud et al. 2011, p.11). Consequently, an inadequate net nutritional status is reflected in lower rates or stagnation of physical growth for children and adolescents, and if the inadequacy is permanent, one consequence among others will be a reduced adult body size (Bogin 2001).

Floud et al (2011) developed a theory[3] that links the nutritional status of a population to the growth in output and the development of the standard of living. For this reason, the study of the nutritional status – in this paper reflected in height – can yield valuable insights into the development of the standard of living and its relation to economic growth.

Our paper adds to the body of literature by broadening the base of knowledge of the nutritional status in continental Europe in the late 17th century and the first half of the 18th century. We estimated secular trends in height for adult and adolescent men born in the Holy Roman Empire (designated[4] HRE or simply Empire from now on). Our estimates of the nutritional status reveal, in the most favorable interpretation, only a minor improvement in the nutritional status towards the first two decades of the 18th century, followed by a decline and a brief recovery of the nutritional status, followed again by a substantial decline. On average, individuals were in a less satisfactory condition in 1760 when compared to 1700. We documented a turning point in the trajectory of stature that is consistent with a decline in stature estimated for other European countries. A regional analysis indicates a divergence in the levels of height after the beginning of the 18th century, resulting in a north-south gradient.

However, the regional secular trends in height are highly correlated between one another, suggesting that some phenomena that had the power to affect the entire HRE are likely to be the probable causes for the trends in nutritional status. We provide evidence that

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[3] "Technophysio Evolution".

[4] We try to avoid the designation "Germany", since this definition is in itself ambiguous and does not reflect the extent of the "Holy Roman Empire of the German Nation".

harvest conditions are a very plausible determinant of our trends. As the 18th century progressed, population growth became yet another important contributing factor.

Our discoveries support the claim of a deterioration of the nutritional status in the second half of the 18th century, thereby corroborating conclusions drawn in previous research. This chapter is organized as follows: Section 2 briefly summarizes the existing literature. Section 3 discusses the data source and the econometric methodology. The overall trend in heights in the HRE is presented in section 4. Estimates of regional trends follow in section 5. The possible channels that explain the trends in height are then discussed in the subsequent chapter.

1.1. Review of the literature.

We briefly summarized the existing literature about European heights in the 17th and first half of the 18th century, followed by a review of the existing literature about stature in the Empire.

A large body of literature exists[5] that estimates the stature of Europeans born in or after the 1740s. And yet, analyses[6] on the nutritional status of Europeans born before 1740 are scarce. For example, the chapter in Floud et al (2011) on "Height, health and mortality in continental Europe, 1700-2100" only cites[7] Komlos (2003) as an example of a paper that contains estimates heights before the early 18th century. So far, the estimates of English heights that go back furthest are Komlos' (1993) estimates of the stature of male English and Irish servants[8] who were transported to colonial America. The oldest of these servants were born in the 1710s. Komlos and Cinnirella (2007) also calculated trends in height for English and Irish males dating back to 1710. Stolz et al. (2013) estimated the height of Portuguese people beginning with a year of birth in the 1720s. Swedish heights were estimated with years of birth beginning in the 1720s (Heintel et al. 1998, Sandberg and Steckel 1980, 1987). A'Hearn's (2003) study of the nutritional status in northern Italy

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[5] See for example, Koch (2012), for an overview.

[6] This discussion pertains to research based on height measured while the individuals were alive. Papers using data on skeletal remains calculate heights for centuries that date back further than the 17th or 18th century. See for example (Steckel 2004, table 1) for an overview. For some regions in Europe, Koepke and Baten (2005) even calculated the height of individuals who must have lived in the 1st century.

[7] Floud et al.'s (2011) statement also refers to the stature of individuals who were measured when alive. They also mention research based on skeletal remains.

[8] Actually, the sample contains also a few servants from Germany, Scotland and Holland (Komlos 1993, table 1), but height trends are only estimated for the English and the Irish servants, as well as for those servants whose country of birth was unknown (Komlos 1993, table 4).

began circa 1730. Other[9] studies of European statures usually focus on individuals born around the second half of the 18th century, the latest example being Komlos and Küchenhoff (2012), who started in the 1740s. Research that estimates the stature of people born in the 17th century is even more seldom. To the best of our knowledge, only two exist thus far: Komlos (2003) estimated the height of members of the French army, with years of birth that date back to the 1660s. The oldest soldiers in Cinnirella's (2008) study of the nutritional status in Saxony were born in the 1690s.

The nutritional status in the 18th century HRE has received little attention in more than one aspect: Koch (2012) estimated a trend in heights for recruits born between 1735 and 1780, but no trend for the entire Empire has been estimated for people born before 1735[10]. Secondly, even regional trends only date back to the 1730s, with Cinnirella's (2008) analysis being the only exception. Baten's (2002) work on the nutritional status in Bavaria and Palatinate also dates to the 1730s. Komlos (1989) has extensively studied the evolution of heights in the south-eastern part of the HRE[11], as well as in regions of the Habsburg monarchy that were not part[12] of the Empire. His earliest estimates begin around the 1730s. Komlos (1990a) has investigated the relationship between stature and social status using a dataset of boys enrolled in a school in what is today south-western Germany. 52% of these boys were born in what was then the Duchy of Wuerttemberg[13] in the Swabian Imperial Circle. Finally, no estimates of the nutritional status exist for years of birth prior to 1690.

1.2. Data and Methodology

We analyzed temporal and geographical variation in height in the Holy Roman Empire[14] and in the French provinces Alsace and Lorraine: The latter two became part of the Kingdom of France in 1648, respectively 1766. Our sample consists of N=80,570 observations.

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[9] See, for example Koch (2012) for an overview.

[10] Stolz et al. (2013) calculate a trend in stature for Europe back to the 1720s. Their region "Central-West Europe" contains Germany and Austria among various other territories, but for the 18th century, the only data source we could identify in their study that is related to Germany is Komlos and Cinnirella (2007).

[11] Lower Austria, Bohemia and Moravia.

[12] Hungary and Galicia.

[13] Own calculations based on Komlos (1990a, table 1).

[14] We do not include the territories in modern day Italy (for example, the Duchy of Milan) for geographic reasons. Detailed definitions of territories and the sources used are described in the data appendix.

1.2.1. Minimum height requirement

A minimum height requirement (MHR) existed in the French army that prevented insufficiently tall individuals from joining the army. Since we conducted estimations with height as the dependent variable, we had to identify the truncation point of the dependent variable that is present in our data[15]. The identification of the correct MHR is necessary to obtain consistent estimates.

Other researchers who worked with data from "Ancien Régime" army regiments arrived at different conclusions concerning the values of the MHR that were in force: Corvisier (1968), identified a minimum height requirement of 62 Fi (167.8 cm). He argued that the MHR was lowered to 61 Fi (165.1 cm) during times of war. While he did not further qualify the temporal dynamics of the MHR, Komlos (2003, footnote 13) explained that the MHR was lowered to 60 Fi (162.4 cm) during the War of the Spanish Succession. Schubert (2008) used various MHR in his study of French militia and soldiers, between 60 Fi (162.4 cm) and 61 Fi (165.1 cm). Schubert and Koch (2011), who analyzed the stature of members of the French militia[16], recruited between 1750 and 1788, used a MHR of 60 Fi (162.4 cm). In addition, they pointed out that this MHR was strictly enforced and remained constant[17] over the years.

The literature cited above all pertains to Frenchmen, and to the best of our knowledge, we were the first[18] researchers to focus exclusively on foreigners who enlisted in the French army. We are not aware of any sources that define a MHR for foreign troops of the French army in particular.

We created several histograms to identify the MHR that was in use in our sample. From the overall distribution of heights, a MHR of 62 Fi (167.8 cm) appears to be the most plausible candidate for the MHR (figure 1).

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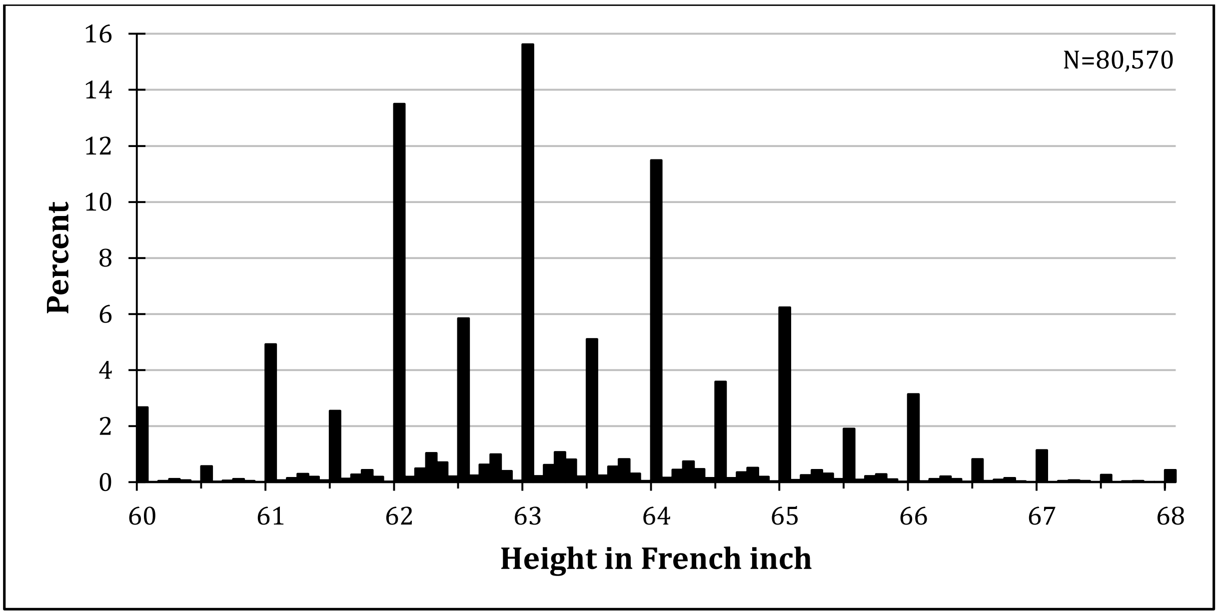
[15] See the econometric methodology section for details.

[16] They also studied soldiers, but the soldiers were recruited in the years 1783 to 1837, so there is almost no overlap with our recruitment years, which end in 1786.

[17] In respect to soldiers, they stated that the MHR was subject to frequent changes (Schubert and Koch 2011, p.278).

[18] Corvisier's (1968) overview of the "Ancien Régime" army records implicitly includes the records that our dataset is based on, but he provides an overview of the data. He did not specifically study foreigners nor did he study heights in detail.

Figure 1: Distribution of heights



Sources: See the text. *Notes*: N=499 observations below 60 Fi (162.4 cm) and N=555 observations above 68 Fi (184.1 cm) are not shown.

What cannot be detected from figure 1 is whether or not the MHR varied[19] between different types of troops: Members of the elite troops called Grenadiers (grenade throwers) had to be taller than ordinary soldiers[20]. In our dataset, N=2,797 soldiers are Grenadiers, with an average height of 65.5 Fi (177.18 cm). The average height of soldiers in our sample who are not Grenadiers is 63.6 Fi (171.03 cm). This difference is significant[21] at the 1% level. In (Komlos 2003), members of special troop companies[22] tended to be taller compared to ordinary soldiers. Komlos reported that unadjusted average heights of members of special troops were 174.6 cm and 169.1 cm for all recruits (Komlos 2003, footnote 16). In his study of Italian regiments of the Habsburg army, A'Hearn (2003) estimated members of a Grenadier category to be 7.8 cm[23] taller than other soldiers. While we do not know more about the definition of Grenadiers in the Habsburg army, his finding corroborates our results. Thus, we investigated whether or not the MHR differs between Grenadiers and other soldiers in our sample (figure 2):

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[19] We thank John Komlos for his advice on the identification of a higher MHR for Grenadiers.

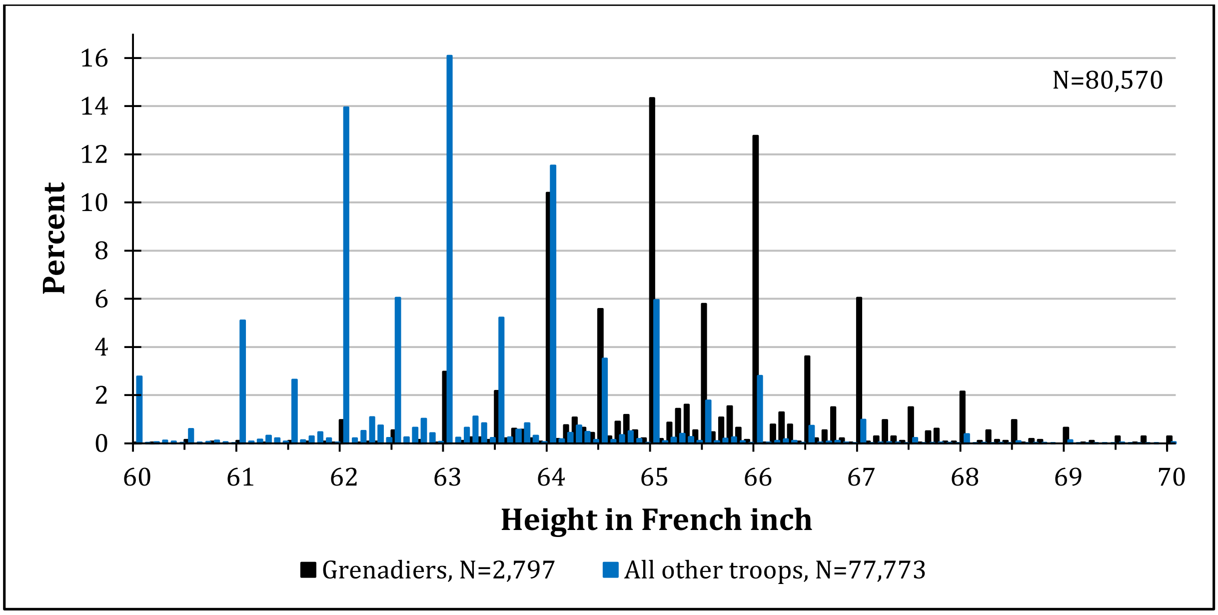
[20] Corvisier (1968, p.83) states this, but he does not specify an actual MHR for Grenadiers. For members of other special companies (Colonelle, Lieutnant Colonelle, Chasseurs), we did not find any sources that speak of a different MHR for these companies in comparison to ordinary soldiers, so we assume that the MHR for them is 62 Fi.

[21] Based on a t-test.

[22] His definition contains other special troops aside from Grenadiers, see Komlos (2003, footnote 16).

[23] A'Hearn (2003, p.364), table 2, based on a restricted TNR.

Figure 2: Distribution of heights, Grenadiers and all other troops



Sources: See the text. *Notes:* N=499 observations below 60 Fi (162.4 cm) and N=80 observations above 70 Fi (189.5 cm) are not shown.

From figure 2, we concluded that for recruits who were not member of the Grenadier companies, the MHR of 62 Fi (167.8 cm) is the most plausible candidate. As far as the MHR for Grenadiers is concerned, 65 Fi (175.9 cm) is the most sensible candidate. 64 Fi (173.2 cm) is not a sensible candidate since the percentage of recruits who are 64 Fi (173.2 cm) tall is lower than one might expect if the data follows a normal distribution: Komlos (2004) argued that the data[24] should be approximately normally distributed between truncation points, but the distribution of heights truncated at 64 Fi (173.2 cm) is not symmetric. The fact that we observed recruits with a height below the assumed MHR at all - can be explained by the fact that MHRs were never strictly enforced (Komlos 2004).

Komlos advised to investigate the distribution of heights separated by age groups: *"In historical populations, those who were older than 23 had reached their final height and can therefore be considered adults. One should analyze the height distributions of younger soldiers separately [...]"* (Komlos, 2004, p.163). Accordingly, we divided our sample into youth (age 16 to 23) and adults (age 24-50[25]) and studied the corresponding distributions of heights (figures 3 and 4).

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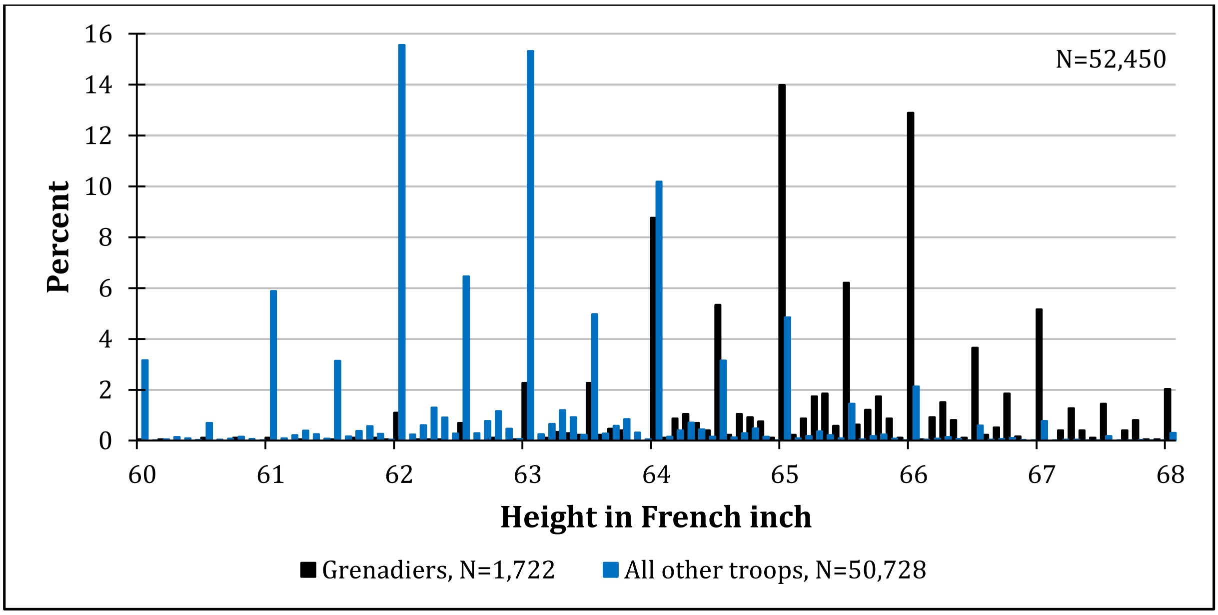
[24] Assuming that a lower and an upper truncation point exist.

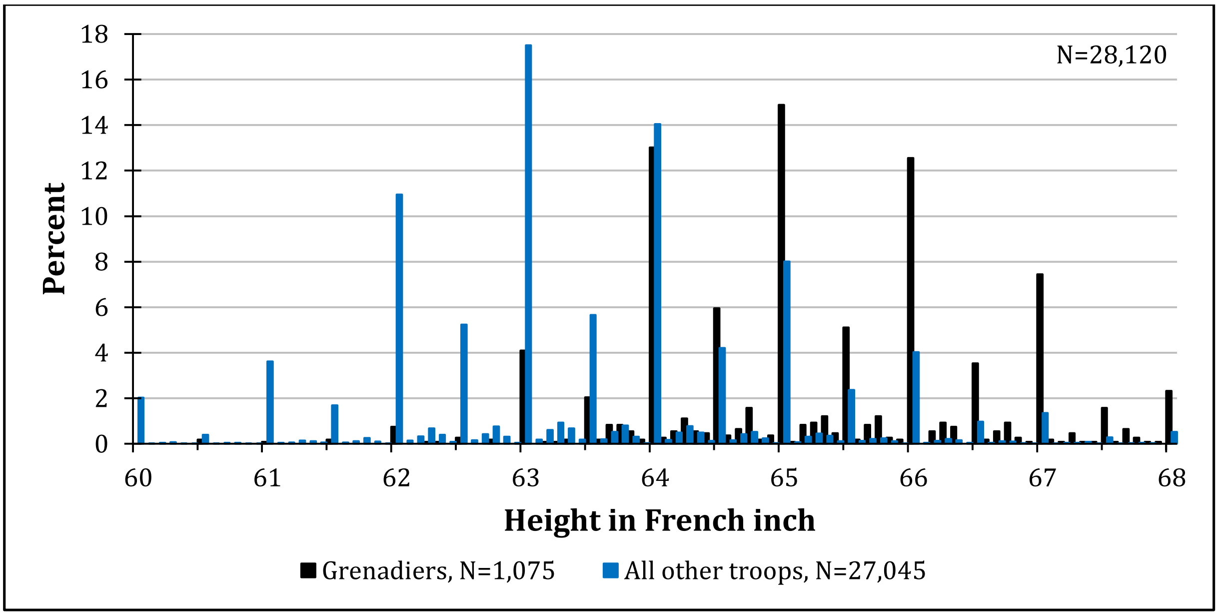
[25] Recruits who were older than 50 years at the date of enlistment were discarded.

Figure 3: Distribution of heights, soldiers age 16 to 23



Sources: See the text. *Notes*: N=383 observations below 60 Fi (162.4 cm) and N=371 observations above 68 Fi (184.1 cm) are not shown.

Figure 4: Distribution of heights, soldiers age 24 to 50



Sources: See the text. *Notes*: N=116 observations below 60 Fi (162.4 cm) and N=238 observations above 68 Fi (184.1 cm) are not shown.

We concluded from figures 3 and 4 that the MHR differs not only between Grenadiers and the other troops, but also that the MHR is different also between different groups of Grenadiers: The MHR was 65 Fi (175.9 cm) for young recruits admitted to the ranks of Grenadiers and only 64 Fi (173.2 cm) for adult Grenadiers. This result may appear counter-intuitive at first, but it can be explained by the reasoning that some adult recruits shorter than 65 Fi (175.9 cm) were allowed to join the Grenadiers because of previous combat experience[26] or other deeds that made them worthy of being a member this elite troop. A transfer of short adult recruits to the Grenadiers from other companies as a reward for merit is also conceivable. Naturally, a recruit who enlisted with 16 or 17 years of age cannot have much experience; therefore, a stricter MHR was probably enforced.

When we divided our sample into enlistment during times of war[27] and enlistment during times of peace (figures 5 and 6), we did not find evidence that the MHR was lowered below 62 Fi (167.8 cm). While the number of observations below 62 Fi (167.8 cm) is higher in times of war (figure 5) than in times of peace (figure 6), an implausibly high increase in the number of recruits who are 62 Fi (167.8 cm) tall compared to those who are shorter is still distinctly visible when soldiers enlist during a war. In particular, when compared to the distribution of heights in Komlos (2003, figure 1) for enlistments between 1740 and 1762, the increase in percentages in Komlos' (2003) figure is substantially less pronounced than in our case[28].

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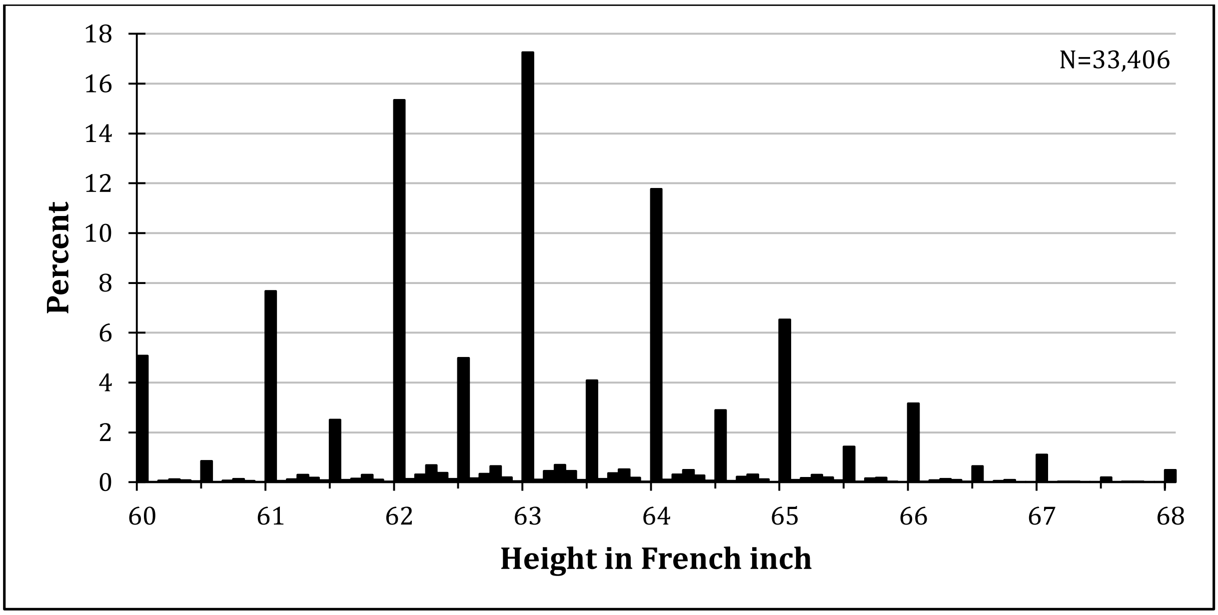
[26] We cannot identify whether our adult recruits have previous combat experience and enlisted in our regiments after having served in other regiments or armies before.

[27] The wars we considered were: Nine Years' War (1688-1697), the War of the Spanish Succession (1701-1714), the War of the Quadruple Alliance (1718-1720), the War of the Polish Succession (1733-1735), the War of the Austrian Succession (1740-1748), and the Seven Years' War (1756-1763). We did not include the Great Northern War (1700-1721) because the Kingdom of France did not participate in this war.

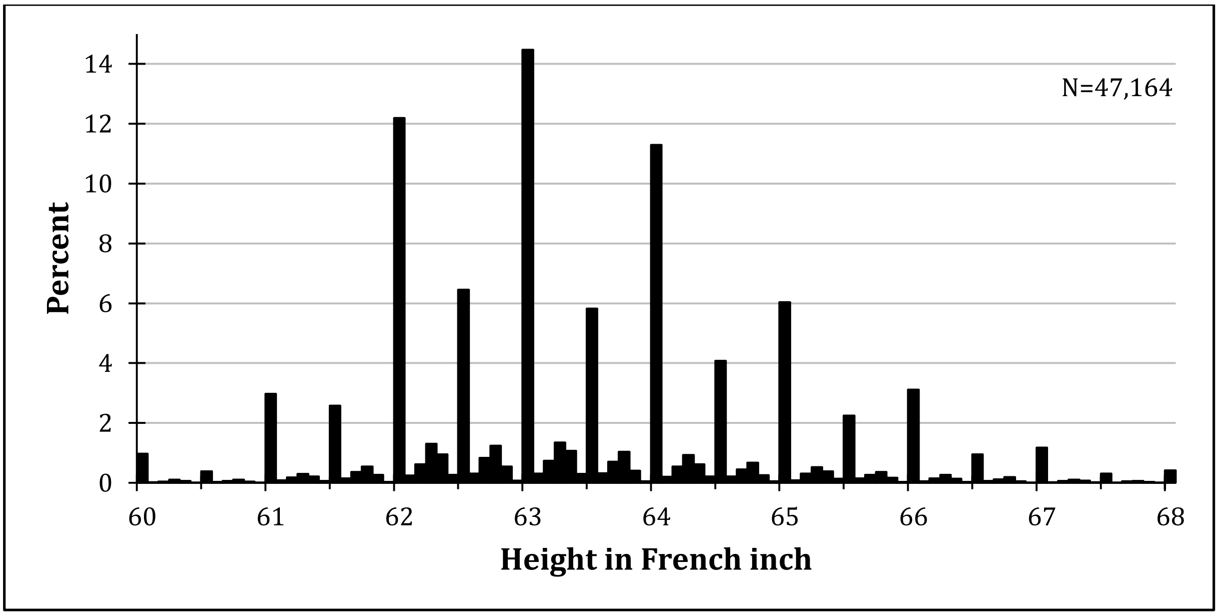
[28] We did not separate our observations any further into finer categories (e.g. adult Grenadiers enlisting during wartime) since the total number of Grenadiers is too low and the corresponding histograms would not be informative.

Figure 5: Distribution of heights of soldiers who enlisted in times of war



Sources: See the text. *Notes*: N=463 observations below 60 Fi (167.8 cm) and N=145 observations above 68 Fi (184.1 cm) are not shown.

Figure 6: Distribution of heights of soldiers who enlisted in times of peace



Sources: See the text. *Notes*: N=36 observations below 60 Fi (167.8 cm) and N=410 observations above 68 Fi (184.1 cm) are not shown.

Our conclusions remained the same when separate histograms for enlistment during one specific war are studied[29]. Only in one case, a MHR of 60 Fi (162.4 cm) or 61 Fi (165.1 cm) could be an alternative to a MHR of 62 Fi: For recruits who enlisted during the War of the Austrian Succession, the MHR could have been lowered to 60 Fi (162.4 cm), as Komlos

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[29] See appendix for histograms.

(2003, footnote 13) reasoned. Nevertheless, we concluded that the histogram does not lend sufficient support to the hypothesis of a lower MHR during the War of the Austrian Succession[30]. Summarizing, we defined the following MHRs (table 1) for our dataset.

Table 1: Assumed MHRs

Troop category	MHR[31] in Fi	MHR in cm
Infantry	62	167.8
Grenadiers, age 16 to 23	65	175.9
Grenadiers, age 24 to 50	64	173.2

Sources: See the text. *Notes:* Results are rounded to one decimal place.

To take into account effects of enlistment during war which do not manifest themselves in a lower MHR, we added a dummy[32] for enlistment during periods of war to all our models.

We discarded all observations below the specified MHRs from the dataset (N=11,726). In discarding all observations below the MHRs, we are in line with other studies that are confronted with a truncated dependent variable, for example Komlos[33] (2003). In addition, we eliminated N=9 recruits who were implausibly tall[34].

Since our dataset contains adults as well as youth, we faced an "end-point-problem" with respect to the years of birth: The final year of recruitment is 1786, so we cannot observe an adult recruit after 1762. So any calculation that predicts adult heights for years of birth after 1762 is therefore an "out of sample[35]" prediction. Because we did not want to calculate such predictions, we discarded all recruits born after 1762 (N=3,992).

64,843 observations remain for the analysis. Before we present any results, we provide a short overview of the econometric methods used throughout the text.

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[30] We show in the appendix that our main results remain valid if we use a lower MHR for recruits who enlisted during the War of the Austrian Succession of if we use a MHR of 64 Fi (173.2 cm) for all Grenadiers.

[31] We always set the truncation points in the estimations to 61.9 Fi (167.5 cm) respectively 63.9 Fi (173.0 cm) or 64.9 Fi (175.7 cm) since our statistical software discards observations exactly at the specified truncation point.

[32] Note that the estimated trends for the entire empire are qualitatively identical if the dummy is left out of the regressions

[33] Note that Komlos (2003) estimated trends with a truncation point of 61.75 Fi (167.1 cm) to account for some rounding around the truncation point (Komlos, 2003, p.166).

[34] Taller than 73 Fi (197.6 cm).

[35] For example, the predicted height of an adult recruit born in 1770 would be based on adults born exclusively before 1763, so the prediction would be based on the observations for youth only.

1.2.2. Econometric Methodology

Adult heights of a homogenous population are asymptotically normally distributed (Bogin, 1999), but due to the MHR, our height data follows a truncated normal distribution. Ordinary Least Squares regressions will produce inconsistent parameter estimates if the dependent variable is truncated (Cameron and Trivedi 2005). All of the methods we used exploit the knowledge of the distributional properties of our dependent variable to correct for the truncation. However, the methods differed in the way the mean of the dependent variable is modeled.

The usual method to analyze truncated normal distributed data is Truncated Normal Regression (TNR), which takes the truncation of the dependent variable into account and yields consistent estimates of coefficients $\boldsymbol{\beta}$ in a linear index: $\boldsymbol{x\beta}$. We estimated the conventional TNR, a method which also estimates the standard deviation of the dependent variable, as well as A'Hearn's (2004) restricted TNR[36], where the standard deviation of the dependent variable is not estimated from the data but constrained to the modern-day value of 6.86 cm[37].

Furthermore, we estimated a "Generalized Additive Model of Location, Scale and Shape" (GAMLSS, Rigby and Stasinopoulos 2005, 2007). The GAMLSS[38] framework allows us to deviate from the conventional estimation strategy in the way the secular trend in height is modeled. These trends are conventionally estimated using birth-cohort dummies. And yet, in more recent research by Komlos and Küchenhoff (2012), as well as by Koch (2012), a different approach is used. Trends are estimated using a spline[39] regression approach. This method enables a flexible estimation of the secular trend ("smoothing") without using birth-cohort-dummies. In a GAMLSS, a linear index of other explanatory variables can be added to the model in addition to the flexibly estimated component. In our flexible specifications, we model $\boldsymbol{y}$ as $y = f(t) + \boldsymbol{x\beta}$ where $\boldsymbol{x}$ is a set of control variables and $f(t)$ is a flexibly estimated function of year of birth t. Such models that combine a set of linear

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[36] A'Hearn (2004) studied the properties of this ML estimator when the standard deviation of the dependent variable is *a priori* fixed to the value that is found among the height distribution of modern populations. A'Hearn (2004) found that this constrained estimator is more precise –as regards the means square error (MSE), that is to say, in terms of the trade-off between bias and variance of the estimate- than the unconstrained version, as long as the imposed standard deviation is close to the true value of the standard deviation. We extended his simulation in chapter 4.

[37] We convert the standard deviation to French inches for the estimation: 2.534482446 Fi (6.86 cm/2.706667 Fi by cm) and use the rounded value of 2.534 Fi in all constrained regressions.

[38] We thank Fabian Scheipl and Helmut Küchenhoff for bringing the GAMLSS model to our attention.

[39] Throughout this and the following chapter, we use a penalized spline of degree 2 as the spline function.

explanatory variables with a flexibly estimated function are known as a "semiparametric generalized linear models" (Hastie and Tibshirani 1990, p.152).

When estimating a model that includes a smoothing term *"[...] there is a fundamental trade-off between the bias and variance of the estimate, and this trade-off is governed by the smoothing parameter."* (Hastie and Tibshirani 1990, p.40). The GAMLSS-framework allows the smoothing parameter to be automatically selected using "Generalized cross-validation" (see Hastie and Tibshirani 1990, Rigby and Stasinopoulos 2005, p.536-537 for details). "Generalized cross validation" asymptotically minimizes the mean squared error of the estimate of the unknown function *f* (Hastie and Tibshirani 1990). One drawback of a model that contains a non-parametrically estimated function in comparison to birth cohort dummies is that inference concerning the flexibly estimated part of the model as well as inference about the significance of coefficients in the linear part, is at best, computationally intensive. Hence, we only show the predicted trend from the smooths we carried out but we do not report the estimated parameters or their standard errors.

The GAMLSS approach does not relax the assumption that the heights are truncated normally distributed. We did not pursue estimation techniques that relax the normality assumption (e.g. Symmetrically Trimmed Least Squares).

Similar to the TNR, the GAMLSS-framework estimates the standard deviation of the dependent variable. In addition to this unconstrained estimation, we also estimated a semiparametric generalized linear model where we fix[40] the standard deviation at 2.534 Fi, analogous to the constrained TNR. We designated this model "constrained spline".

While the GAMLSS framework also allows for a flexible estimation of the standard deviation of the dependent variable, we did not pursue such an approach because we are unaware of any research in anthropometrics where the standard deviation of heights is modeled explicitly and not assumed constant.

All estimations were conducted with height in French inch as the dependent variable. When our estimations were based on a sample that contains youth, we added dummy variables for ages below 24 to account for the unfinished growth process of the recruits.

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[40] Technically, we set a starting value of the standard deviation estimate in the GAMLSS-model to 2.534 Fi and suppress the optimization with respect to this parameter.

By defining all recruits who are older than 23 as adults, we are in accordance with Komlos (2004).

In addition to the regression results, we calculated predicted heights for soldiers born in different years respectively birth cohorts. In these predictions, where applicable, the age controls received a weight of zero. The coefficients of all other dummy variables except birth cohorts received weights according to their respective sample proportions. Regression results and predicted heights are displayed in cm using a conversion factor of 1 Fi = 2.706667 cm as in Komlos (2003, footnote 5). We used heteroscedasticity-robust[41] standard errors in all truncated regressions.

1.3. Descriptive statistics

We assigned all territories[42] within the HRE to their designated Imperial Circle. In some cases, we combined the observations of territories within a given Imperial Circle than belonged to different branches of noble houses[43]. It should be noted that the designations of the circles do not necessarily correspond to the designations of modern-day states bearing the same name[44]. Koch (2012, chapter 2) categorized the soldiers in his sample also into Imperial Circles, with some exceptions[45].

The distribution of our recruits across their Imperial Circles of birth indicates an overweight of circles or regions that are close to the French border (figure 7, table 2) or were part of the Kingdom of France. Most recruits in our dataset were born in the Alsace[46], followed by Lorraine and Upper Rhine. Lower Saxony is the least represented circle in our sample (figure 7 and table 2).

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[41] We also considered using clustered standard errors with clustering at the Imperial Circle level, but the number of clusters is too low to ensure that such standard errors are reliable. Angrist and Pischke (2009) recommend using clustered errors when the number of clusters is around 40 at least. This number would be substantially lower in our regressions.

[42] See the data appendix for a detailed discussion.

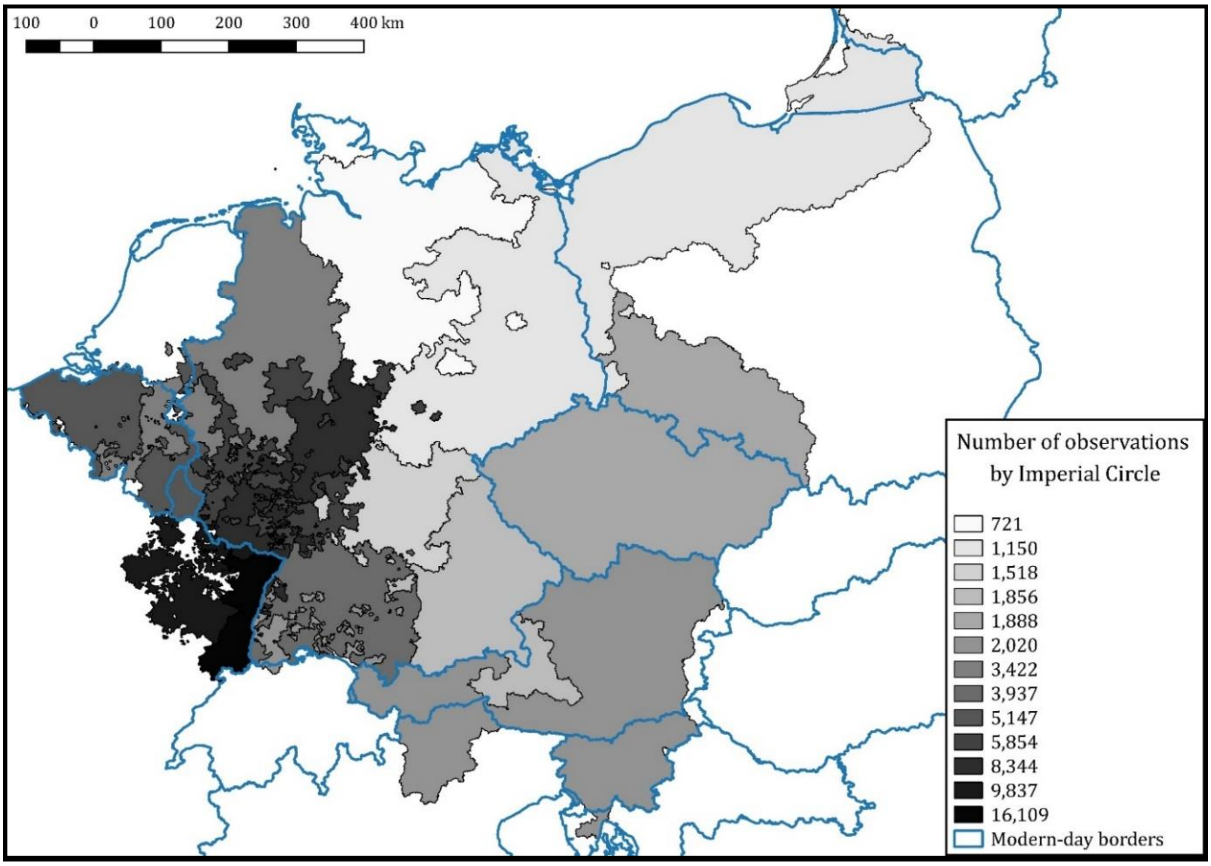
[43] To reduce heterogeneity of the geographical information on the level below Imperial Circle, we made some simplifying assumptions and extensions. See appendix and the data appendix for details.

[44] For example, by “Bavaria” we mean the Bavarian Imperial Circle, which overlaps only in part with the present federal state Bavaria in the Federal Republic of Germany. This restriction is true for all Imperial Circles.

[45] See, e.g. Koch (2012, p.57, table 2).

[46] The reason why we treat Alsace and Lorraine separately and do not assign it to an Imperial Circle is the fact that they were ceded to France shortly before or during the period we studied. See the data appendix for details.

Figure 7: Distribution of soldiers across their Imperial Circles of birth



Sources: See the text. Maps are our own creation in QGIS based on existing shapefiles. *Sources and copyrights for the map:* See appendix. *Notes:* N=3,040 observations that could not be assigned to an Imperial Circle are not shown.

Table 2: Descriptive statistics

	N	Percent
Imperial Circle of birth		
Only HRE[47]	3,040	4.70
Alsace	16,109	24.8
Lorraine	9,837	15.2
Upper Rhine	8,344	12.9
Electoral Rhine	5,854	9.0
Burgundia	5,147	8.0
Swabia	3,937	6.1
Westphalia	3,422	5.3
Austria	2,020	3.1
Bohemia[48]	1,888	2.9
Bavaria	1,856	2.9
Franconia	1,518	2.3
Upper Saxony	1,150	1.8
Lower Saxony	721	1.1
Decade of birth		
1644-1669	52	0.1
1670-1679	222	0.4
1680-1689	1,027	1.6
1690-1699	2,646	4.1
1700-1709	4,539	7.0
1710-1719	7,332	11.3
1720-1729	14,238	22.0
1730-1739	10,334	15.9
1740-1749	9,157	14.1
1750-1759	12,485	19.3
1760-1762	2,811	4.3
Age at enlistment		
16 to 23	39,409	60.80
24 to 50	25,434	39.2
Decade of enlistment		
1683-1699	40	0.1
1700-1709	101	0.2
1710-1719	1,711	2.6
1720-1729	4,218	6.5
1730-1739	4,019	6.2
1740-1749	15,668	24.2
1750-1759	11,563	17.9
1760-1769	10,982	17.0

Table continues on the next page

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[47] This category contains observations where we could not assign an Imperial Circle, but it is very plausible that the recruits were born in the Holy Roman Empire.

[48] We use this term to describe all “Lands of the Bohemian Crown”, that is to say Bohemia (N=1,113), Silesia (N=558, we do not differentiate between the parts of Silesia that were ceded to Prussia in 1742 and those retained by Habsburg) and Moravia (N=217). Note that the “Lands of the Bohemian Crown” are not an Imperial Circle.

Table 2, continued

	N	Percent
Decade of enlistment		
1770-1779	13,229	20.4
1780-1786	3,312	5.1
Recruit's occupation		
Unknown or not recorded	58,101	89.6
Production and related, transport equip	3,978	6.1
"Sans vacation"[49]	1,638	2.5
Laborer	526	0.8
Professional, technical and related	239	0.4
Agricultural, animal husbandry and forest	174	0.3
Service	126	0.2
Other[50]	61	0.1
Father's occupation		
Unknown or not recorded	64,390	99.3
Production and related, transport equip	245	0.4
Laborer	93	0.1
Agricultural, animal husbandry and forest	41	0.1
Service	35	0.1
Other[51]	39	0.0
Religion		
Unknown or not recorded	44,221	68,2
Catholic[52]	15,236	23.5
Not Catholic[53]	5,384	8.3

Sources: See the text. *Notes:* Results are rounded to one decimal place. Occupational categories are based on HISCO (van Leeuwen et al. 2002) with own extensions where no HISCO category applies.

With years of birth dating back to 1644, and the resulting low number of observations, a robust inference on the existence of trends in height can be expected to begin at best around 1680 in regressions where all observations are pooled.

Enlistments occurred over the course of more than 100 years, but before 1710 they are not frequent. Koch (2012), described the army as an employer of last resort. He analyzed a sample of recruits that was the result of a mixture of recruiting systems (voluntary and

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[49] This is an ambiguous category. The term may mean "unemployed" or "does not need to work". See the data appendix for details.

[50] Contains the occupations: "Student" (N=32), "Sales" (N=22), "Clerical and related" (N=4), "Pupil" (N=2) and "Bourgeois" (N=1).

[51] Contains the occupations: "Sales" (N=18), "Professional, technical and related" (N=10), "Bourgeois" (N=5). "Clerical and related" (N=4), "Sans vacation" (N=1) and "retired or private gentleman" (N=1).

[52] Contains N=2 observations designated "Lutheran converted to Catholic".

[53] Contains observations with the following designations for religion: "Lutheran" (N=3,801), "reformed church" (N=1,473), "Evangelist" (N=67), "Calvinist" (N=35) and "Protestant" (N=8).

conscription), while our recruits enlisted voluntarily. In his sample, the number of ordinary workers is much higher compared to our sample[54].

Given that religion of the soldiers was recorded, we have a strong overweight of Catholics in our sample, as has Koch (2012), but the share of Protestants in our sample is substantially higher than in Koch's sample. One explanation for this are the different geographical regions represented in his sample: In his sample, recruits from the catholic Habsburg possessions have constitute almost 60% of the total number of observations.

1.4. Secular trend in height using observations from the entire Empire

We began by estimating trends for the HRE as one, where observations of all soldiers, adults and youth, born in any part of the Empire, are pooled. Then, we estimated trends for a subset of the data that pertains only to adults.

Members of special troop companies exhibit marked differentials in height (table 3, all models). The results concerning height differential of special troops are similar to the aforementioned results by Komlos (2003) and A'Hearn (2004).

The growth pattern for young recruits is consistent with expectations: Younger recruits tend to be shorter (table 3, models 1 and 2) than recruits who enlisted as adults. Even 23-year old are still significantly shorter than adults. This result is in accordance with Komlos' (2004) statement that recruits who are older than 23 can be considered adults in terms of a completed growth process. The height differentials between adults and youth we estimate are in some cases comparable, and in other cases more pronounced than in other studies. Cinnirella (2008) estimates 18-year olds to be 5.89 cm shorter than adults[55], and our constrained estimate is of a similar magnitude, yet his 20 year olds are only 1.1 cm shorter than adults. In his sample, recruits who were older than 20 years stopped growing. The same is true for the age coefficients that Koch (2012) calculated. He estimated 22-year old recruits to be significantly *taller* than adult recruits, by 0.66 cm. Koch's (2012) estimates of age effects are also of a much smaller magnitude compared to our estimates. Yet, it should be noted that the differences in heights we estimate are of a

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[54] A more detailed discussion of the occupational information can be found in the data appendix.

[55] His definition of adults starts with age 23. The coefficients of dummy variables for ages 21 and 22 are both not significantly different from zero in his regressions, so the growth process of the recruits in his sample might have been completed earlier than the growth process of recruits in our data.

much smaller magnitude than the differences in height that can be computed based on Komlos' (1990a) paper about German boys who were students at an elite school in Stuttgart: For example, the difference in average height between a 21-year old boy and a 16-year old boy, both from the middle class and born in 1758/1769 is 12.3 cm[56]. Thus, the youth in our sample had more to "catch up" in stature towards adults than a comparable group had in other papers, though the size of our estimated age effects is not unprecedentedly large. The dummy variable for enlistment during a war is always significant and has -the expected negative sign. We hypothesize that the coefficient of this dummy captures average demand effects of enlistment during times of war.

Table 3: Estimation results based on observations from the entire Holy Roman Empire

Dependent variable: Height in cm	Adults and youth			Adults		
	(1)	(2)	N	(3)	(4)	N
Troop category						
Light troops[57]	-1.9***	-2.4***	1,240	-3.4***	-4.6***	305
Lieut. Colonelle	0.7***	0.8***	4,260	0.5**	0.6**	1,545
Colonelle	4.3***	5.2***	6,421	3.7***	4.9***	2,739
Grenadiers	4.8***	4.3***	2,123	4.1***	3.6***	956
Infantry	Ref.		50,799	Ref.		19,889
Age						
Age 16	-6.1***	-7.6***	2,045			
Age 17	-6.0***	-7.5***	4,380			
Age 18	-4.3***	-5.3***	6,433			
Age 19	-2.8***	-3.5***	6,238			
Age 20	-1.9***	-2.4***	6,485			
Age 21	-0.8***	-1.0***	4,576			
Age 22	-1.2***	-1.5***	5,106			
Age 23	-0.7***	-0.9***	4,146			
Age 24-50	Ref.		25,434			
Birth cohort						
1644-1679	-0.6	-0.7	274	-0.2	-0.3	253
1680-1689	-1.6***	-1.9***	1,027	-1.1***	-1.5***	967
1690-1699	-0.9***	-1.2***	2,646	-0.6**	-0.8**	1,775
1700-1704	Ref.		2,215	Ref.		1,094
1705-1709	-0.3	-0.4	2,324	-1.2***	-1.6***	1,271
1710-1714	-1.1***	-1.4***	2,957	-1.2***	-1.6***	1,785
1715-1719	-1.7***	-2.1***	4,375	-1.7***	-2.3***	3,069

Table continues on the next page

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[56] Calculated from Komlos (1990a, p.613, table 2, column "middle class", years of birth 1758/69). Average heights are: At age 21: 168.4 cm; at age 16: 156.1 cm.

[57] Original designation: "Chasseurs".

Table 3, continued

Dependent variable: Height in cm	Adults and youth			Adults		
	(1)	(2)	N	(3)	(4)	N
Birth cohort						
1720-1724	-2.1***	-2.6***	6,988	-2.2***	-3.0***	3,960
1725-1729	-2.8***	-3.5***	7,250	-1.6***	-2.2***	2,341
1730-1734	-2.1***	-2.5***	5,352	-0.5*	-0.7*	1,969
1735-1739	-0.4*	-0.5*	4,982	0.1	0.2	1,674
1740-1744	0.4*	0.5*	4,444	1.2***	1.6***	1,404
1745-1749	0.7***	0.9***	4,713	1.8***	2.4***	1,322
1750-1754	1.2***	1.5***	5,783	1.4***	1.9***	1,460
1755-1759	-0.4*	-0.4*	6,702			
1760-1762	-2.0***	-2.5***	2,811			
1755-1762				0.9***	1.3***	1,090
Imperial Circle						
Alsace	Ref.		16,109	Ref.		4,393
Lorraine	1.1***	1.4***	9,837	0.9***	1.2***	2,687
Upper Rhine	2.2***	2.7***	8,344	1.7***	2.3***	2,692
Electoral Rhine	2.1***	2.6***	5,854	1.5***	2.0***	2,455
Burgundia	2.2***	2.7***	5,147	1.6***	2.2***	2,737
Swabia	1.2***	1.5***	3,937	0.6***	0.9***	1,808
Westphalia	2.0***	2.5***	3,422	1.6***	2.2***	1,691
Only HRE	1.9***	2.4***	3,040	1.1***	1.5***	1,625
Austria	0.9***	1.1***	2,020	0.2	0.3	1,014
Bohemia	0.2	0.2	1,888	-0.2	-0.2	1,261
Bavaria	1.1***	1.4***	1,856	0.8***	1.1***	1,094
Franconia	0.9***	1.2***	1,518	0.5*	0.7*	805
Upper Saxony	1.9***	2.4***	1,150	1.3***	1.8***	707
Lower Saxony	2.4***	2.9***	721	1.8***	2.5***	465
Enlistment circumstance						
Enlistment during war	-1.0***	-1.2***	26,606	-0.8***	-1.1***	12,082
Enlistment during peace		Ref.	38,237		Ref.	13,352
Constant	168.5***	166.2***		169.4***	166.2***	
Sigma	5.9***	constrained		5.4***	constrained	
Log-Likelihood	-95,122.6	-95,294.1		-39,659.2	-39,869.1	
N			64.843			25,434

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In models (2) and (4), Sigma was constrained to 2.534 Fi (6.86 cm).

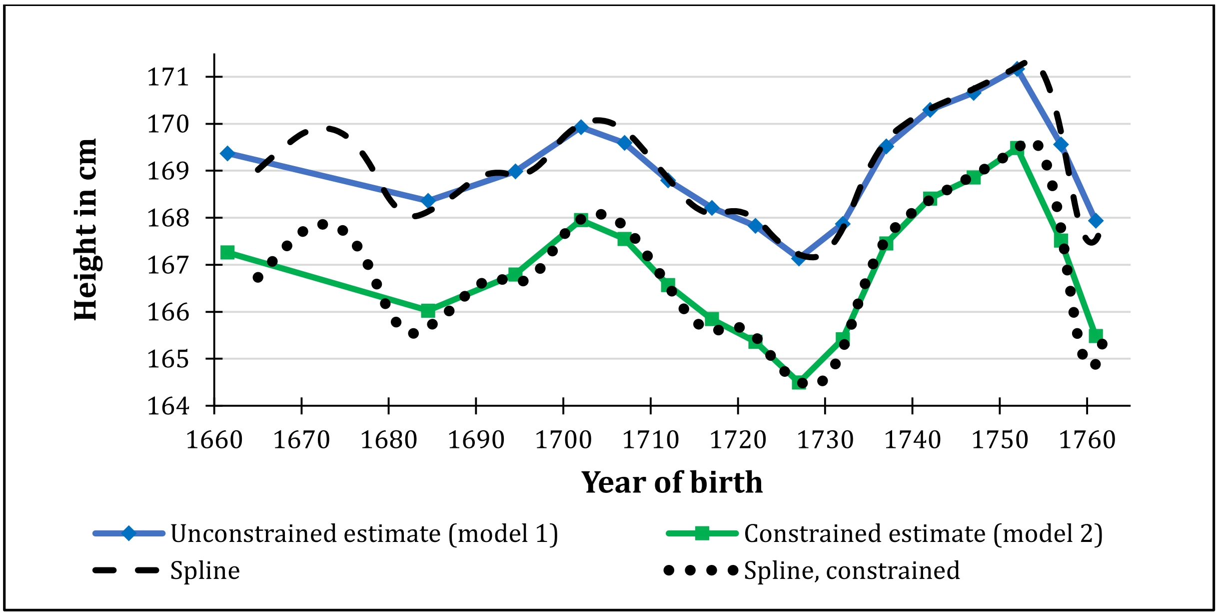
Table 3.1 Predicted heights based on regression results in table 3.

	Adults and youth						Adults					
Birth cohort	Model 1	95% Confidence interval		Model 2	95% confidence interval		Model 3	95% Confidence interval		Model 4	95% Confidence interval	
1644-1679	169.4	168.3	170.4	167.3	166.0	168.5	170.3	169.3	171.2	167.4	166.1	168.6
1680-1689	168.4	167.8	168.9	166.0	165.4	166.6	169.3	168.8	169.9	166.1	165.5	166.8
1690-1699	169.0	168.6	169.4	166.8	166.4	167.2	169.9	169.5	170.3	166.9	166.4	167.3
1700-1704	169.9	169.5	170.3	168.0	167.5	168.4	170.5	170.0	170.9	167.6	167.1	168.2
1705-1709	169.6	169.2	170.0	167.6	167.1	168.0	169.2	168.7	169.8	166.0	165.4	166.6
1710-1714	168.8	168.4	169.2	166.6	166.1	167.0	169.3	168.8	169.8	166.1	165.5	166.6
1715-1719	168.2	167.8	168.6	165.8	165.5	166.2	168.8	168.3	169.2	165.3	164.9	165.8
1720-1724	167.8	167.5	168.2	165.4	165.0	165.7	168.3	167.9	168.6	164.6	164.2	165.0
1725-1729	167.1	166.8	167.5	164.5	164.1	164.9	168.9	168.4	169.3	165.5	165.0	165.9
1730-1734	167.9	167.5	168.3	165.4	165.0	165.8	170.0	169.5	170.4	167.0	166.5	167.5
1735-1739	169.5	169.2	169.9	167.5	167.1	167.8	170.6	170.2	171.0	167.8	167.3	168.3
1740-1744	170.3	170.0	170.6	168.4	168.1	168.8	171.7	171.3	172.1	169.3	168.8	169.8
1745-1749	170.7	170.3	171.0	168.9	168.5	169.2	172.3	171.9	172.6	170.0	169.5	170.5
1750-1754	171.2	170.9	171.5	169.5	169.2	169.8	171.9	171.5	172.3	169.5	169.0	170.0
1755-1759	169.6	169.2	169.9	167.5	167.1	167.9						
1760-1763	167.9	167.4	168.5	165.5	164.9	166.1						
1755-1763							171.4	170.9	171.9	168.9	168.3	169.5

Sources: See the test. *Notes:* Predictions were carried out in French inch and converted into centimeters. Results were rounded to one decimal place

Heights declined in the second half of the 17th century, until a local minimum is reached in the 1680s. A subsequent period of recovery followed, ending around 1705. This recovery was immediately offset by a sharp decline in heights, leading to an all-time low in stature, reached circa 1730. A second period of recovery follows suite, but these gains in height are lost again after the second half of the 1750s. Height levels are about 2 centimeters lower during the period 1760-1762, than in the first decade of the century (table 3, model 1 and figure 8).

Figure 8: Predicted height of soldiers born within the HRE



Sources: See the text and table 3.1. *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Spline regressions were restricted to years of birth after 1664.

Trends estimated using constrained regressions are identical in shape when compared to unconstrained estimates, but the level of predicted heights is lower by circa 2 cm (tables 3 and 3.1, model 2 and figure 8).

The predictions based on flexible specifications closely[74] follow the trends based on models 1 and 2, except for years of birth before 1680 (figure 8). The predicted trend based on the constrained spline estimate is almost identical to the unconstrained spline

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[74] When we flexibly estimate a trend in height using the total span of years of birth, the predicted height trend aligns to our estimates using birth cohort dummies (model 1) after 1664. Yet, for earlier years of birth, the spline regression predicts implausibly tall recruits. Consequently, we re-estimate the spline regression, but we discard recruits born before 1665. Note that we will pursue the same strategy of exclusions in all spline regressions where we consider it necessary.

estimate, but the level of heights is shifted down, similar to the "shift" between the unconstrained and constrained dummy regressions.

We find significant and sizeable differences in predicted heights between some Imperial Circles (table 4, figure 9). Recruits from the north and center of the HRE (Lower and Upper Saxony, Upper and Electoral Rhine, Burgundia and Westphalia) are significantly taller than recruits from the southern regions of the Empire. Recruits from Alsace are the shortest, followed closely by recruits from Bohemia. Our results are comparable to Koch's (2012) and Coppola's (2009) findings. Koch (2012) documents a north-south gradient for a space of time that partially overlaps with ours, and Coppola's (2009, p.96, figure 10) conclusions are analogous, although the recruits are not categorized into imperial circles[75].

We explore in more depth the heterogeneity between the Imperial Circles in an ensuing section, estimating trends on a disaggregated level.

Table 4: Predicted heights by Imperial Circle

Imperial Circle	Predicted height	95% Confidence interval	
Lower Saxony	168.2	167.4	169.0
Upper Rhine	168.0	167.8	168.3
Burgundia	168.0	167.7	168.3
Electoral Rhine	167.8	167.5	168.1
Westphalia	167.8	167.4	168.2
Upper Saxony	167.7	167.0	168.3
Swabia	166.8	166.5	167.2
Lorraine	166.7	166.4	167.0
Bavaria	166.7	166.2	167.2
Franconia	166.5	165.9	167.0
Austria	166.4	165.9	166.9
Bohemia	165.5	165.0	166.1
Alsace	165.3	165.0	165.5

Notes: Predicted heights based on model 2. *Notes:* Predictions were carried out in French inch and converted into centimeters. All variables are weighted by their sample proportions except age controls, which receive zero weight. Results were rounded to one decimal place.

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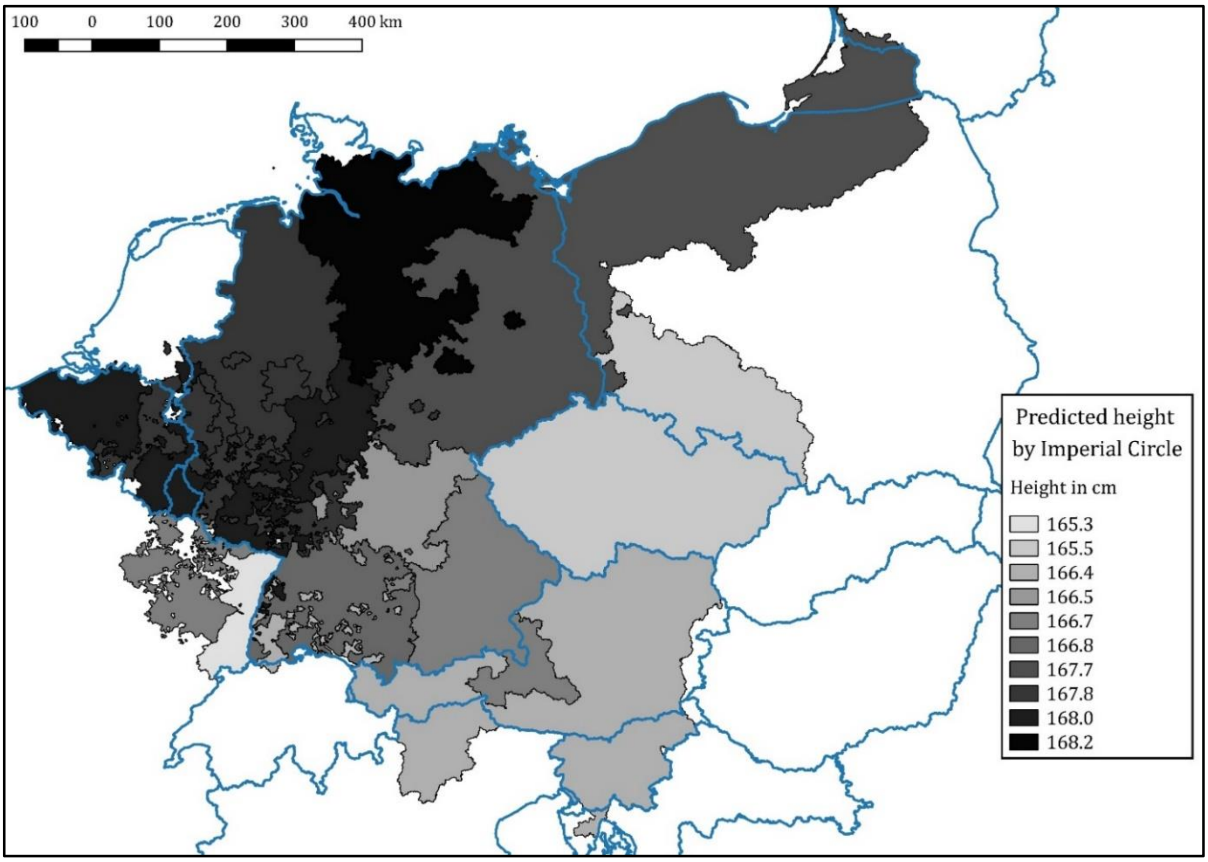
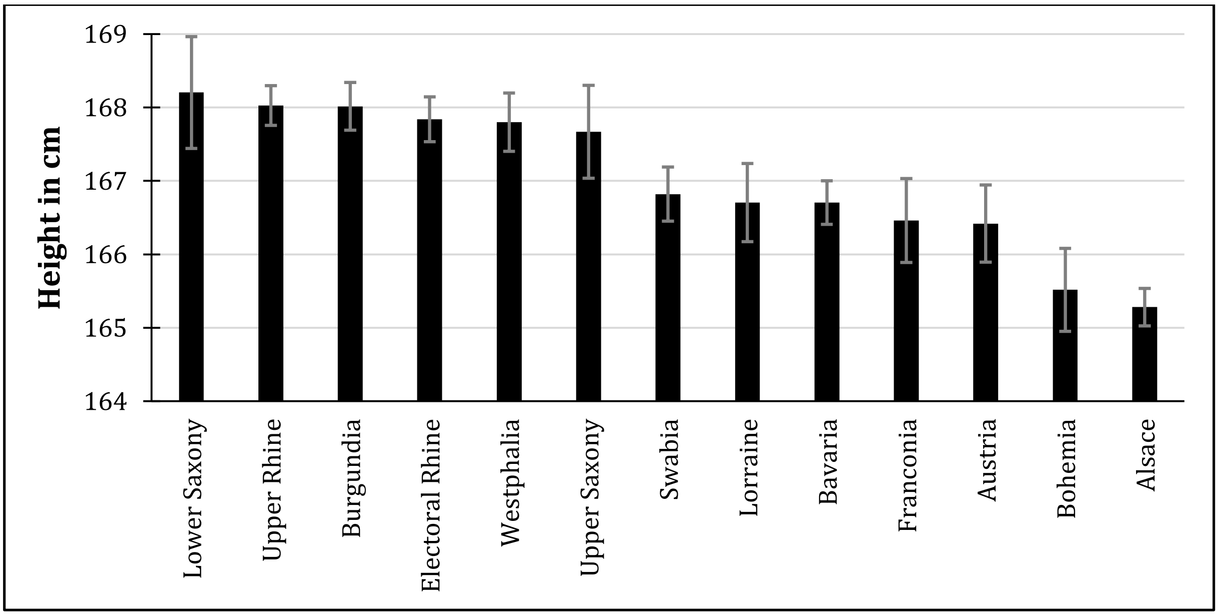
[75] The circles ceased to exist before the period studied in the paper by Coppola. (1815-1840).

Figure 9: Predicted heights by Imperial Circle



Sources: See the text and table 4. Maps are our own creation in QGIS based on existing shapefiles. *Sources and copyrights for the map:* See appendix.

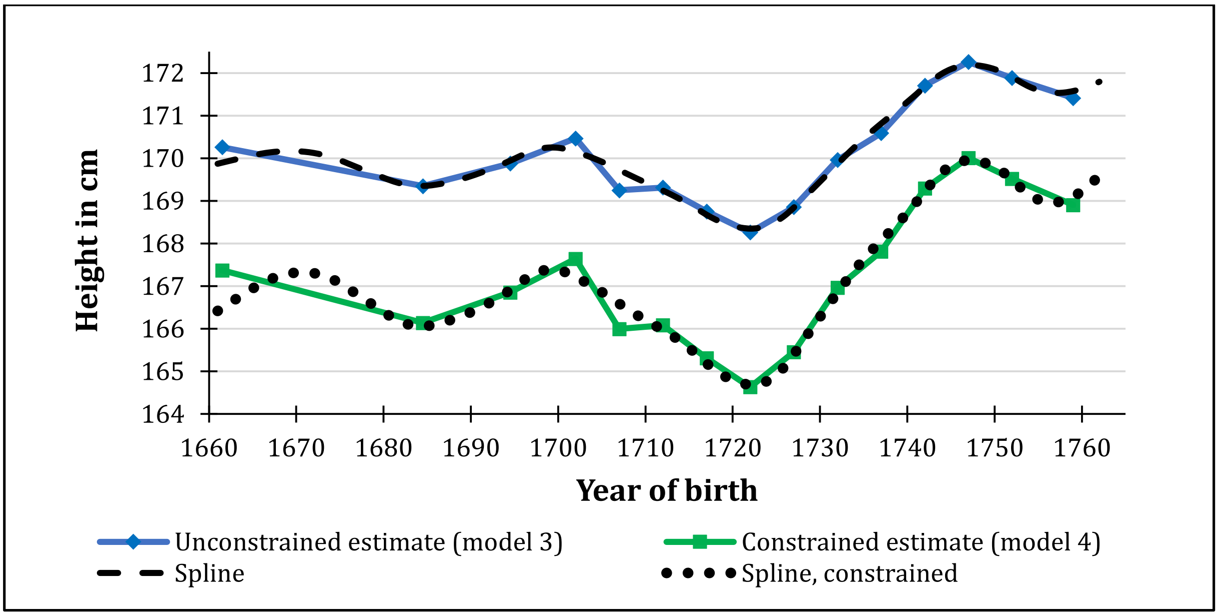
Figure 10: Regional distribution of heights



Sources: See the text and table 4. Predictions are based on model 2. *Notes:* Grey bars indicate the 95% confidence interval.

The estimated trends in stature using the subset of adult recruits are similar to the trends based on the whole dataset. Yet, the decline in heights predicted after 1754 is not as pronounced in the models using only adult recruits (tables 3 and 3.1, figure 11). The differences in stature between the Imperial Circles are less pronounced compared to the reference group than when the main dataset is used (table 3). Spline regressions[76] closely follow the trend based on dummy variables.

Figure 11: Predicted height of recruits born within the HRE, adults subsample



Sources: See the text and table 3.1. *Notes:* The sample used in our calculations consisted of adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Spline regressions were restricted to years of birth after 1660.

The results from models (1) and (2) are robust[77] when we change the MHR to 64 Fi (173.2 cm) for all Grenadiers. In addition, if we assume that the MHR was lowered to 60 Fi (162.4 cm) during the War of the Austrian Succession, all our main findings remain valid, with predicted heights[78] that are qualitatively comparable to the results we just presented. We also tested whether the inclusion of controls for the regiment of enlistment changed the results. The overall shape of the estimated trends is qualitatively identical to the results we have presented so far (figures 8 and 11), and only the predicted levels of heights are slightly different[79].

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[76] For the same reasons as in the previous spline regressions, we exclude early and late years of birth from the spline regressions.

[77] See table A1 and figure A4 in the appendix.

[78] See table A2 and figures A6, A7 in the appendix.

[79] See table A3 and figures A8, A9 in the appendix.

Bodenhorn et al. (2015) criticize[80] the conclusions drawn based on samples using individuals who enlisted in the military under a voluntary enlistment system. They argue that the decision to enlist is driven by labor market conditions, so a secular trend in height estimated based on such samples may just reflect differences in the "quality" of recruits who enlisted at different dates.

We estimated models using observations of adults where we included controls for the decade of enlistment to assess the effect of the timing of recruitment on our results. The inclusion of dummies for the decade of enlistment changed the results, in particular the increase in height after 1720 (table 3, models 3 and 4) is not present when we include dummies for the decade of enlistment. Nonetheless, the trends for recruits born before 1720 are similar to the models we have estimated so far[81]. Furthermore, the estimated impacts of the decade of enlistment on height are contrary to the prevailing labor market conditions proxied by real wages at that time, so we do not consider the models that include enlistment controls as convincing given our dataset. A detailed discussion[82] can be found in the appendix.

1.4.1. National and international comparison

The existing literature allows us to compare our results to estimates from other regional studies with respect to the Empire as well as papers that estimate height other nations in the 17th and 18th century. In this section we focus on nation-wide estimates. Existing knowledge derived from regionally confined datasets[83] is compared to our regional specific estimates that follow. We also compared our results to the "Central-West European[84]" trend estimated by Stolz et al. (2013), since it dates back to 1720 and contains observations for Germany[85].

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[80] We thank Sebastian Wichert for bringing this paper to our attention.

[81] See table A4, and figure, A10 in the appendix.

[82] This discussion includes also a finding that the introduction of a reward for tallness that was paid at enlistment is not overly relevant for the estimated trends.

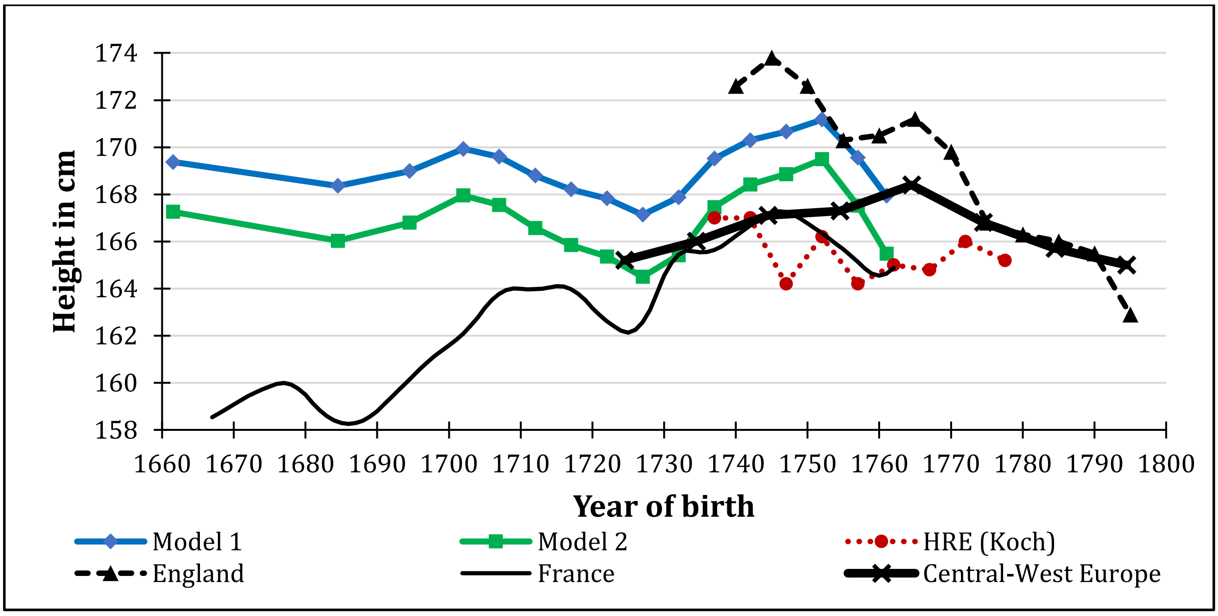
[83] For example, the evolution of stature in the Kingdom of Saxony by Cinnirella (2008), or the analysis of the nutritional status in the eastern part of the Habsburg Empire by Komlos (1989). Comparisons of these studies with our predictions follow in the next section.

[84] "Central-West Europe" consists of Germany, Austria, the Netherlands, the UK, Ireland, France and Sweden (Stolz et al. 2013).

[85] But for data on the 18th century, we could only identify Komlos and Cinnirella (2007) as the data source used by Stolz et al. (2013) that pertains to Germany and is used to construct the Central-West European height estimates.

Koch's (2012) estimated trends in height in the HRE for a period that partly overlaps with ours. We compared our results to re-estimated trends based on Komlos' (2003) study of early modern France, since his predictions date back to the middle of the 17th century, as ours. England received much attention in the literature, thus a comparison of our results to estimates of English heights was also performed.

Figure 12: Predicted height of recruits born in the HRE, France, England and Central-West Europe



Sources: Models 1 and 2: See the text. HRE (Koch): (Koch[86] 2012) England: (Komlos and Küchenhoff[87] 2012). France: Re-estimation[88] of (Komlos 2003). Central-West Europe: (Stolz et al. 2013).

Our estimates differ substantially from trends based on Komlos' (2003) data, in both the constrained as well as in the unconstrained case (figure 12). French heights started at a considerably lower level and gradually increased towards the heights we predict using

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[86] We read off the values from: (p.60, figure 4: "Whole territory, dummy regression"), so they should be considered approximations.

[87] We read off the values from: (p.51, figure 1: "Army and Marines, MHR 66 unconstrained"), so they should be considered approximations.

[88] Predicted heights are based on a semi-parametric additive model with an unconstrained standard deviation. The coded data was kindly provided by John Komlos. Regression is based on recruits aged 16 to 50 and born before 1763. MHR of 61.9 Fi (167.5cm) was used throughout (Constrained regressions were on average at a 0.5 cm lower level but followed an identical trend. Constrained are qualitatively identical if a MHR of 63.9 Fi (173.0 cm) is used instead for Grenadiers. Unconstrained regressions follow a qualitatively similar trend, but exhibit a marked level-shift in this case). The trend in heights was estimated using a spline, additional control variables for ages 16 to 23, for Komlos definition of Grenadiers and for the province of birth were added. In the prediction, age controls receive zero weight. All other covariates are weighted by sample proportions. It should be noted that in terms of the level of heights, our re-estimations of Komlos' (2003) are lower, between 1 and 2 centimeters when compared to the original results. In all, this may be the result of a different estimation technique: Komlos uses TOLS regression, while we use a GAMLSS. However, the actual trend is similar to Komlos' (2003) original (p.168, figure 2).

the constrained regression for the Empire. After 1720, a co-movement of our trend estimate and the re-estimated trend based on Komlos (2003) is clearly visible, though the sharp increase and subsequent decline of heights after 1720 is more pronounced in our estimates when compared to the results for France. The overall[89] correlation between our estimates for the HRE and our re-estimates of Komlos (2003) is 0.34 (significant at 1%). When we restrict our attention to years of birth after 1709, the correlation[90] increases to 0.82 (significant at 1%). Nevertheless, the turning points of the trends are slightly different between France and the Empire. Frenchmen already began to shrink around 1745, and subjects of the emperor follow this trend approximately 10 years later (figure 12).

Our predicted heights are similar to Koch's (2012) results in 1735 and again in 1760. On the other hand, he does not predict the inverted "U-shape" in the trend we estimate for the period 1735 to 1760.

Recruits born the second half of the 18th century were shorter than their predecessors born in the beginning of the century. This interpretation is confirmed by the fact that towards the end of the years we study, our predicted heights are again close to what Koch (2012) estimated.

Englishmen had always had a height premium in comparison to subjects of the Emperor when we compare their stature to the height we predict using the constrained estimator. Soldiers born in the Empire grew almost as tall as Englishmen in the 1750s when we compare their heights to our unconstrained estimates (figure 12). English stature began to decline some ten years before the decline also began in the HRE. Our results are also compatible to the "Central-West European" trend estimated by Stolz et al. (2013). The turning point in stature we estimate predates the one they estimated, but a perfect correspondence cannot be expected since "Central-West Europe" contains a heterogeneous list of countries. Before we discuss the possible determinants of our

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[89] Results are based on unconstrained spline regressions for the HRE and France using years of birth 1667 to 1762.

[90] French heights in (Komlos 2003) are also highly correlated with heights in other European territories. Komlos (2003) interprets this finding as an indication that the trends were not caused by a variation in recruitment practices. However, since our estimates are somewhat sensitive to the inclusion of enlistment controls, we do not know whether the aforementioned statement generalizes to our dataset. Yet, in the appendix we provide supplementary evidence that support the conclusion that our predictions are not driven by enlistment effects.

findings, we first estimated region-specific trends to shed a light on possible regional differences in the nutritional status.

1.5. Regional trends

Regional differences in stature are a common phenomenon[91]. Our estimation strategy in the preceding sections only allowed us to identify differences in the level of heights between Imperial Circles. Whether the secular trends in stature differ between regions cannot be concluded from the regressions we have heretofore estimated.

In addition, existing estimates of the nutritional status in the 18th century Empire are regionally confined, so a comparison with our trends for the entire HRE is not very informative. Consequently, we now estimate trends in stature on a more regional scale. Using the results from table 4 and figure 10, we combined Imperial Circles with comparable heights and estimate trends for each of the "regions" separately. We combined both Saxon circles into a region that represents the "Eastern[92]" part of the Empire. We also joined Burgundia, Upper Rhine, Westphalia and Electoral Rhine which represent the Central-Western region of the HRE. Bavaria, Swabia and Franconia combined the represent the southern part of the Empire. The Habsburg territories[93] consist of Austria and Bohemia. Although the predicted heights for Alsace and Lorraine are significantly different from one another, (table 4) and predicted heights differ by 1.4 cm, we combined these two territories into a "Frontier Zone", because of their geographical proximity and since both were under French dominion.

A comparison of the trends we estimate for each region[94] is presented at the end of the following section. Our predictions based on constrained estimates are more comparable

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[91] See Steckel 1995 for an overview over regional differences in height in the United States and Komlos (2003) for differences in stature between historical provinces in the Kingdom of France.

[92] Note that predicted heights between these circles are not different from one another (table 4) at the 5% percent level.

[93] We are aware of the fact that most of the territories in Burgundia are also part of the Habsburg territories and were actually assigned to the Austrian Habsburgs after the War of the Spanish Succession (Köbler 2007), but due to the large geographical distance to the other Habsburg territories, we do not combine Burgundia with Austria and Bohemia.

[94] Note that the number of observations used in the regressions for each region may be higher than the sum of the corresponding numbers of observations for the respective circles in table 2. The reason is that observations that cannot be assigned to a circle (collected in "Only HRE" in table 2) can in some cases be attributed to regions that span more than one circle. This is the case when the stated territory of birth corresponds to a landscape, for example.

to the results of other studies[95], so in the following figures, we only depict the predictions based on constrained regressions.

1.5.1. East

In the regression for the eastern part of the Empire, we had to exclude all Grenadiers and light troops since they were not present with a sufficiently high number of observations (N=32 and N=24 respectively). Furthermore, we combined the age categories into two-year cohorts and the estimated trends were based on 10-year birth cohorts instead of 5-year birth cohorts because the number of observations by birth cohort was considerably lower in this subsample. Concerning information about the recruit's occupation, only in N=202 cases any occupation[96] was recorded, with N=131 cases being "Production and related". This left too little variation in occupation to include this variable in the regressions. The same is true for the religion of a recruit. It was stated in N=630 cases, with only N=140 Catholics and N=490 non-Catholics. This is consistent with what one would expect where the religious distribution in Eastern HRE is concerned, but again the number of testified denominations is not sufficiently high to include them in a regression. Unfortunately, this pattern of having an insufficient number of observations with respect to any of the supplementary variables is also present in regressions for the other regions, so we cannot add these variables as controls in any of the regional regressions.

The estimated trends in height for the East are similar to the overall trend we estimated for the HRE, except that we do not find a strong decline in heights after the 1750s (table5, figure 13), but only a slight and insignificant one. Nevertheless, a turning point in the trend is visible, in congruence with the trend estimated for the Empire in total. The Eastern region is the only region we analyze where we do not find a pronounced decline. The trends based on spline regressions yields a trend in heights that is compatible to the previous results (figure 13). Constrained and unconstrained[97] estimations are again alike, only the levels of predicted heights differ[98].

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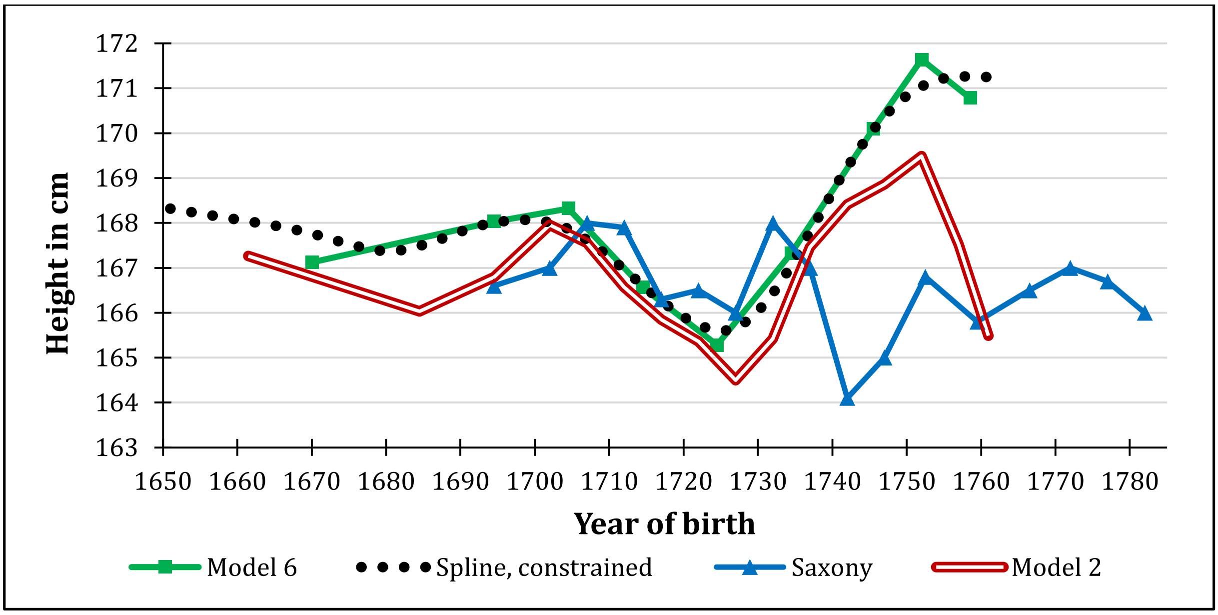
[95] Because these studies also primarily used the constrained estimator.

[96] The occupation of the recruit's father was stated in only one case.

[97] Not show in figure 13.

[98] On average by 2.9 cm.

Figure 13: Predicted height of soldiers born within the Eastern region of the HRE



Sources: See the text and tables 3,5, HRE: Koch (2012), Saxony: Cinnirella[99] (2008). *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted at the middle of the respective cohort. Predicted heights from model 5 followed an almost identical trend, but were on average 2.7 cm larger.

Except for recruits born in the Electorate of Saxony, we do not find significant differences in heights between the territories in the Eastern region of the HRE. Furthermore, the estimated coefficients do not follow a geographical pattern (table 5). Two results are remarkable: Firstly, the coefficients of Imperial Cities are positive, albeit insignificant, contrary to the negative effect[100] one would expect (Komlos 1998). Secondly, soldiers born in the Electorate of Saxony are considerably shorter than recruits from any other Eastern territory. This may appear at first glance contrary to the results about Saxony by Cinnirella's (2008). He drew a positive conclusion about the nutritional status of Saxons[101] until 1770. However, the coefficient of the dummy variable for the Electorate of Saxony in our regressions measures the difference in mean heights of soldiers born in the Electorate of Saxony relative to recruits from the Hohenzollern possessions[102]. Therefore, in our interpretation the coefficient we estimated does not contradict Cinnirella's (2008) findings, since our estimates only imply that recruits from "Brandenburg-Prussia" had an

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[99] We read off the values from: Figure 3, p.242: "average height", so they should be considered approximations.

[100] Also called "urban penalty" in the literature.

[101] Cinnirella (2008) estimates a trend exclusively for Saxony, so his results cannot be generalized to recruits from other eastern parts of the Empire.

[102] That is to say "Brandenburg-Prussia" and territories in the eastern part of the Empire that they acquired.

even better nutritional status compared to Saxons. Saxony was among the early industrializing regions of the Empire (Cinnirella 2008), and "Brandenburg-Prussia" was not very densely populated[103] (De Vries 1976), so shorter Saxons are in line with the well-known fact that the nutritional status declined with the onset of the Industrial Revolution (Komlos 1993a, 1993b, 1998). Altogether, our predictions fit[104] well to Cinnirella's (2008) until circa 1735. During the ensuing period of recovery, our trends start to diverge from Cinnirella's. While the recovery of heights in our sample continues well into the 1750s, the nutritional status in Cinnirella's sample worsens. He identified the War of the Austrian Succession as a possible explanation. Nevertheless, heights immediately recover in his sample[105], and furthermore, he did not find an effect on the nutritional status of the Seven Years' War. Cinnirella (2008) argued that despite the negative consequences this war had on the population and the economy, it did not reduce the nutritional status since the war acted as a Malthusian check.

Table 5: Estimation results: East subsample

Dependent variable: Height in cm	Adults and youth		
	(5)	(6)	N
Troop category			
Lieut. Colonelle	0.9	1.3	139
Colonelle	4.1***	5.5***	323
Infantry	Ref.		1,763
Age			
Age 16 to 18	-5.0***	-7.1***	111
Age 19 to 21	-1.9***	-2.6***	411
Age 22 and 23	-0.5	-0.7	321
Age 24-50	Ref.		1382
Birth cohort			
1651-1689	1.3*	1.8*	159
1690-1699	2.0***	2.7***	244
1700-1709	2.2***	3.0***	258
1710-1719	0.9	1.3	297
1720-1729	Ref.		484
1730-1739	1.5**	2.0**	269
1740-1749	3.5***	4.8***	210

Table continues on the next page

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[103] We discuss the cross-sectional variation in height in a latter section.

[104] The fact that our constrained estimates fit Cinnirella's predictions can be explained by the fact that Cinnirella's estimates are also based on constrained estimations. Not that we cannot estimate a separate trend for the Electorate of Saxony due to the small sample size.

[105] In a different study on the stature of Saxons, Komlos and Cinnirella (2007) find an increase in the stature of Saxons of some 2 centimeters in the 1740s, more in line with our results. However, the level of heights they estimate is markedly below what we estimate.

Table 5, continued

Dependent variable: Height in cm	Adults and youth		
	(5)	(6)	N
Birth cohort			
1750-1754	4.7***	6.4***	132
1755-1762	4.0***	5.5***	172
Territorial controls			
Hohenzollern possessions	Ref.		421
Unknown[106]	-0.3	-0.5	400
Electorate of Saxony	-1.7***	-2.4***	363
Electorate of Hannover	0.8	1.0	266
Only Lower Saxony[107]	-0.6	-0.8	251
Ernestine Territories	-0.2	-0.2	208
Free or Imperial Cities	0.3	0.3	158
Only Upper Saxony[108]	-0.5	-0.7	158
Enlistment circumstance			
Enlistment during war	-1.0***	-1.4***	1,017
Enlistment during peace	Ref.		1,208
Constant	169.0***	165.5***	
Sigma	5.3***	constrained	
Log-Likelihood	-3,490.7	-3,513.9	
N			2,225

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In model (6), Sigma was constrained to 2.534 Fi (6.86 cm).

1.5.2. Central-West

Since the number of observations in the subset that pertains to the Center and West of the Empire is substantially higher compared to the previous region, we can use a specification that is identical to the one we used to estimate trends in the entire Empire[109]. The results align with the main text results, and in comparison to the results for the Eastern part of the HRE, the gains in height after 1730 are to a large extent offset again by an immediate decline in stature of a similar magnitude (figure 14). Height levels are comparable to the predictions for the East. Spline regression results are almost identical to the dummy

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[106] Due to the ambiguity of the territorial information, it is only known that recruits were born either in the Upper or Lower Saxon Circle.

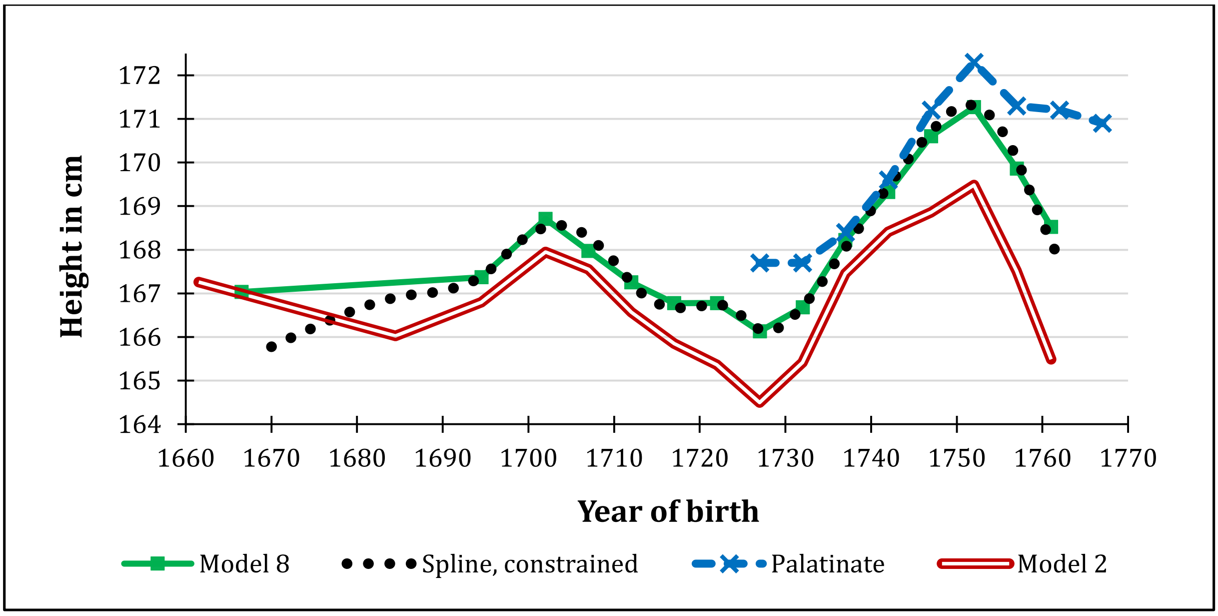
[107] Contains observations where it is only known that recruits were born in the Lower Saxon Circle and recruits from territories with a small number of observations in the Lower Saxon Circle.

[108] Contains observations where it is only known that recruits were born in the Upper Saxon Circle and recruits from territories with a small number of observations in the Upper Saxon Circle.

[109] We did not include religion, for it is missing in 65% of cases, or occupation, which is missing in 87% of cases as explanatory variables.

variable specification. Height differentials between the different territories of birth are again unsystematic and not always significant. The coefficients for "Imperial Cities" are noteworthy, since they now have the sign one would expect if an "urban penalty" existed in the Empire, though they still remain insignificant. We are unaware of other studies regarding the nutritional status for a region comparable to Central-West HRE, except for Baten (2002), who estimated heights for the Palatinate[110]. He also estimated a steep increase in stature after 1730, but the ensuing decline is substantially less pronounced when compared to our predictions (figure 14).

Figure 14: Predicted height of recruits born in Central-Western HRE



Sources: See the text and tables 3,6; Palatinate: Baten[111] (2002). *Notes*: The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Predicted heights from model 7 and unconstrained spline estimates followed an almost identical trend, but were on average 2.4-2.5 cm larger. Spline estimates were restricted to years of birth after 1669.

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[110] The estimations for the Palatinate are contained in his paper on heights in Bavaria. This is due to the fact that the territories of the Electoral Palatinate and Bavaria were in possession of the same noble house after 1777. Note that the Palatinate in his sample is not identical to the Electorate, since the shape of territories was altered after the Final Recess of the Imperial Deputation (Reichsdeputaionshauptschluss) and the Bavarian Palatinate then contained more territories in the western part of the HRE, but not the entire Electorate.

[111] We read off the values from: (p.18, figure 3, "Palatinate, RSMLE, all army categories" in combination with p.17, table 3), so they should be considered approximations.

Table 6: Estimation results: Central-West subsample

Dependent variable: Height in cm	Adults and youth		
	(7)	(8)	N
Troop category			
Light troops	-1.7***	-2.3***	345
Colonelle	3.9***	5.0***	2,384
Grenadiers	4.9***	4.3***	821
Lieut. Colonelle	0.5**	0.6**	1,486
Infantry	Ref.		17,731
Age			
Age 16	-6.6***	-8.9***	609
Age 17	-6.2***	-8.2***	1,243
Age 18	-4.2***	-5.6***	1,956
Age 19	-3.2***	-4.2***	2,076
Age 20	-2.1***	-2.8***	2,286
Age 21	-1.0***	-1.4***	1,627
Age 22	-1.1***	-1.5***	1,837
Age 23	-0.8***	-1.0***	1,558
Age 24-50	Ref.		9,575
Birth cohort			
1644-1689	0.2	0.3	458
1690-1699	0.4	0.6	944
1700-1704	1.5***	1.9****	767
1705-1709	0.9***	1.2***	743
1710-1714	0.4	0.5	923
1715-1719	0.0	0.0	1,400
1720-1724	Ref.		2,061
1725-1729	-0.5*	-0.6*	2,468
1730-1734	-0.1	-0.1	2,201
1735-1739	1.1***	1.4***	2,130
1740-1744	2.0***	2.5***	2,001
1745-1749	3.0***	3.8***	1,694
1750-1754	3.5***	4.5***	1,838
1755-1759	2.4***	3.1***	2,247
1760-1763	1.3***	1.7***	892
Territory			
Habsburg possessions	Ref.		5,000
Pfalz-Zweibrücken	0.3	0.4	2,790
Bishopric of Liège	-0.5*	-0.6**	2,012
Electoral Palatinate[112]	-0.7***	-0.9***	1,771
Electorate of Mainz	-0.3	-0.4	1,479
Hesse	0.2	0.2	1,276
Electorate of Trier	0.1	0.1	1,178

Table continues on the next page

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[112] Includes the Duchies of Jülich and Berg which were owned by the same noble house as the Electorate.

Table 6, continued

Dependent variable: Height in cm	Adults and youth		
	(7)	(8)	N
Territory			
Nassau	-0.1	-0.2	1,147
Bishopric of Speyer	-1.5***	-2.0***	1,099
Unknown Palatinate[113]	-0.8***	-1.1***	1,094
Electorate of Cologne	1.1***	1.4***	755
Free or Imperial Cities	-0.2	-0.2	662
Other Ecclesiastical Territories[114]	0.4	0.5	546
County of Leyen	0.1	0.2	325
Leiningen	-0.6	-0.7	300
Small Territories[115]	0.0	0.0	286
Baden[116]	2.6***	3.4***	205
Imperial Knights[117]	0.7	0.9	177
Hohenzollern possessions	0.2	0.2	137
Only Westphalia[118]	0.4	0.6	130
Salm	0.4	0.5	125
Wied	-1.4*	-1.9*	117
Sayn	0.4	0.5	93
Unknown[119]	-1.4	-1.8	63
Enlistment circumstance			
Enlistment during war	-0.7***	-0.9***	9,525
Enlistment during peace		Ref.	13,242
Constant	169.4***	166.7***	
Sigma	5.6***	constrained	
Log-Likelihood	-34,865.7	-34,996.1	
N			22,767

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In model (8), Sigma was constrained to 2.534 Fi (6.86 cm).

The similarity between the trends we estimate and Baten's results[120] is striking: His sample[121] is a 50/50 mixture of volunteers and draftees, and it includes upper-class

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[113] It is sufficiently clear that recruits came from some part of Palatinate, but it is unclear which territory.
[114] This group contains small and medium sized ecclesiastical territories, including Imperial Abbeys.
[115] This group contains small secular territories.
[116] The House Baden possessed various territories outside their main territories east of the Rhine in the southwestern part of the Empire.
[117] Lower nobility.
[118] Contains observations where it is only known that recruits were born in the Westphalian Circle.
[119] It is only known that recruits were born in one of the Central-West Circles.
[120] Baten also estimates trends for subgroups where certain army categories were excluded, but they are analyzed using a different statistical method so we chose as comparison group Baten's predictions that we considered most comparable to our results in terms of the statistical method.
[121] In addition to the predictions depicted in figure 14, Baten also analyzed a later time period that does not overlap with ours and where the recruitment system was different.

officers and NCOs who had in the majority of cases an urban middle class background (Baten 2002). This similarity between our results and Baten's adds additional support[122] to our conclusion that selection effects are not a prominent contributing factor to our estimated trends.

1.5.3. South

The trends for the southern regions of the HRE are the first ones to deviate markedly from the previously estimated trends. Heights stagnated[123] from the second half of the 17th century to the first decade of the 18th century, followed by a steep decline in stature until a minimum is attained in the 1720s. The following "inverted U" trend is again in agreement with the trends found in existing research (figure 15). On the whole, during this recovery, heights just reach the level in 1700, but do not surpass[124] it as does the stature in East and Central-West (figures 13, 14 and 15). Our spline model again closely follows the dummy variable trend. The age trend exhibits an irregularity: The coefficients of age 21 are insignificant, but 22 year olds were estimated to be shorter than adults (table 7). The coefficients of Imperial Cities were negative and for the first time significant. Baten (2002) estimated trends in stature for Bavaria for an era that partially coincides with ours. He predicted a trend that is very similar to our predictions, except that Bavarians in his sample were taller[125] (figure 15). He also found that the nutritional status of Bavarians in the first half of the 18th century was actually higher compared to inhabitants of the Palatinate, which is part of our Central-West region. However, in our sample, soldiers born circa 1700 in the "Central-West" region were approximately as tall as soldiers born in the Southern HRE., and subsequently, the recruits born in the Central-West surpass Bavarians in height.

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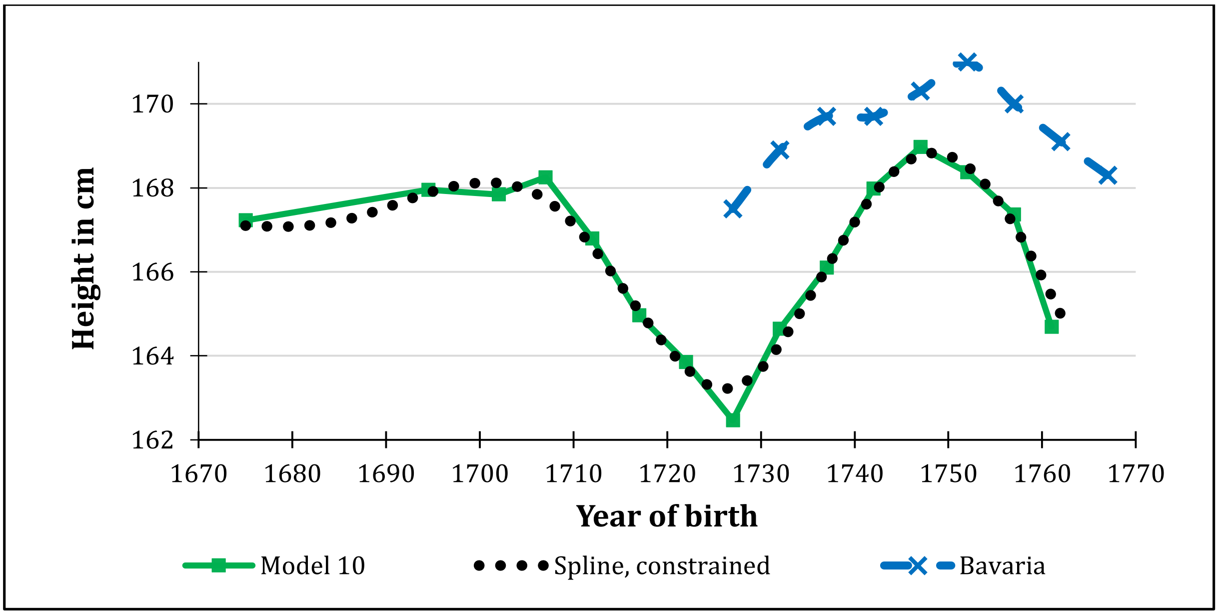
[122] Baten also estimated heights for a southern section of the Empire. In the subsequent section we show that our trends for the southern part of the Empire are again in line with his findings. This is yet another indication that our results are not an artifact of selection.

[123] Differences in coefficients before the 18th century are not significant.

[124] Any difference in the respective coefficients is not significant.

[125] Note that our unconstrained estimates are even closer to Baten's predictions in terms of the levels than our constrained estimates.

Figure 15: Predicted height of recruits born in Southern HRE



Sources: See the text and table 7; Bavaria: Baten[126] (2002). *Notes*: The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Predicted heights from model 9 and unconstrained spline estimates followed an almost identical trend, but were on average 3.5 cm higher. Spline regressions were restricted to years of birth after 1674.

Table 7: Estimation results, South subsample

Dependent variable: Height in cm	Adults and youth		
	(9)	(10)	N
Troop category			
Light troops	-3.1***	-4.5***	110
Colonelle	3.4***	4.7***	793
Grenadiers	4.3***	3.3***	95
Lieut. Colonelle	1.6***	2.2***	435
Infantry	Ref.		5,878
Age			
Ages 16 and 17	-5.0***	-7.4***	239
Age 18	-2.5***	-3.6***	409
Age 19	-2.2***	-3.2***	537
Age 20	-1.2***	-1.8***	679
Age 21	0.3	0.5	521
Age 22	-1.0***	-1.4***	663
Age 23	0.1	0.1	556
Age 24-50	Ref.		3,707

Table continues on the next page

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[126] We read off the values from: (p.18, figure 3: "Bavaria, RSMLE, all army categories" in combination with table 3), so they should be considered approximations.

Table 7, continued

Dependent variable: Height in cm	Adults and youth		
	(9)	(10)	N
Birth cohort			
1661-1689	2.3***	3.4***	228
1690-1699	2.9***	4.1***	470
1700-1704	2.8***	4.0***	373
1705-1709	3.1***	4.4***	376
1710-1714	2.0***	2.9***	387
1715-1719	0.8	1.1	544
1720-1724	Ref.		932
1725-1729	-0.9*	-1.4*	972
1730-1734	0.5	0.8	469
1735-1739	1.5***	2.2***	315
1740-1744	2.9***	4.1***	380
1745-1749	3.6***	5.1***	407
1750-1754	3.1***	4.5***	535
1755-1759	2.4***	3.5***	630
1760-1762	0.6	0.8	293
Territory			
Wuerttemberg	Ref.		1,284
Electorate of Bavaria	-0.6*	-0.8*	1,043
Baden	-1.3***	-1.8***	901
Only Swabia[127]	-0.4	-0.5	679
Only Bavaria[128]	-0.3	-0.5	566
Free or Imperial Cities	-1.4***	-2.1***	488
Other Ecclesiastical Territories	-0.8*	-1.1*	456
Bishopric of Würzburg	-0.8*	-1.1*	444
Hohenzollern possessions	-0.7	-1.1	345
Only Franconia[129]	-0.5	-0.7	254
Small Territories	-0.2	-0.2	244
Bishopric of Bamberg	0.1	0.2	198
Fürstenberg	-0.7	-1.0	171
Imperial Knights	-1.0	-1.5	105
Palatine Duchies[130]	-1.6*	-2.2*	91
Unknown[131]	0.6	0.8	42

Table continues on the next page

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[127] Contains observations where it is only known that recruits were born in the Swabian Circle.
[128] Contains observations where it is only known that recruits were born in the Bavarian Circle.
[129] Contains observations where it is only known that recruits were born in the Franconian Circle.
[130] Smaller, but independent territories of House Wittelsbach ("Pfalz-Sulzbach" and "Pfalz-Neuburg").
[131] It is only known that recruits were born in one of the Southern Circles.

Table 7, continued

Dependent variable: Height in cm	Adults and youth		
	(9)	(10)	N
Enlistment circumstance			
Enlistment during war	-1.1***	-1.5***	2,985
Enlistment during peace	Ref.		4,326
Constant	168.7***	164.7***	
Sigma	5.2***	constrained	
log-likelihood	-10,775.1	-10,847.3	
N			7,311

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In model (10), Sigma was constrained to 2.534 Fi (6.86 cm).

1.5.4. Habsburg territories

Estimated trends for the Habsburg possessions[132] are closely related to the trends we estimated for the southern part of the HRE (figure 16), but not identical. Heights significantly increased in the last decades of the 17th century, instead of stagnated, but afterwards, the development of the nutritional status is similar to the South. Yet, the regression results imply that some of the coefficients are not precisely estimated. For example, the estimated coefficient for Grenadiers in the constrained specification is small relative to previous estimates (table 8), and not even significant. Light troop coefficients are also insignificant. This may be the results of too few observations for these special troops. A geographical pattern in stature can be detected, but it is not completely regular. Recruits born in southern parts of Austria (Tyrol and the "Southeast") are taller than recruits born in the center (Upper and Lower Austria), or the East (Bohemia, Moravia, Silesia), but the estimated difference between "Southeast" and Bohemia is not significant. Our findings imply that Silesians are not significantly shorter than Bohemians. This does not apply to Hungary and Galicia, as Komlos (1989) demonstrated. Koch (2012) estimated a trend for the Habsburg possessions in the HRE. Our results for the 1740s and 1750s are in line with his predictions (figure 16).

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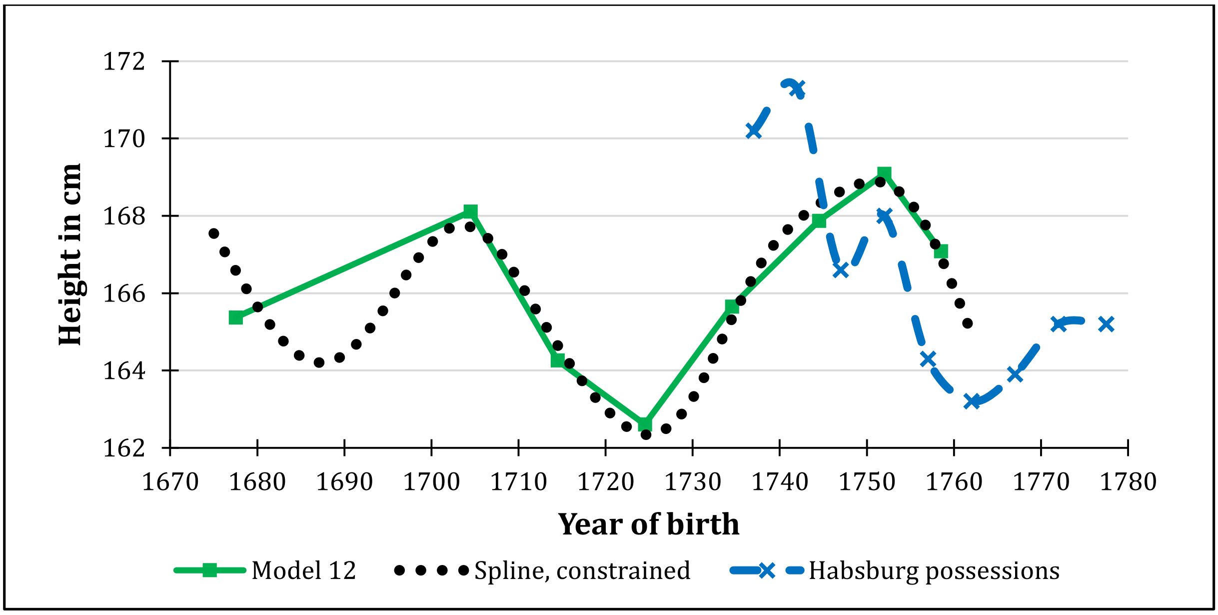
[132] The Austrian Circle contained small ecclesiastical territories, for example exclaves of the bishopric of Freising. We did not try to single out these territories; instead they are absorbed into the surrounding larger territorial units. Even for the larger ecclesiastical territories ones like the bishoprics of Brixen and Trento we did not have enough observations to include them with a separate dummy in the regression. Hartmann (1995) states that the ecclesiastical territories were unimportant in the Austrian Circle.

Figure 16: Predicted height of soldiers born in the southern Habsburg possessions



Sources: See the text and table 8; Habsburg possessions: Koch[133] (2012). *Notes*: The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Predicted heights from model 11 and unconstrained spline estimates followed an almost identical trend, but were on average 3.0-3.3 cm shorter. Spline regressions were restricted to years of birth after 1674.

Table 8: Estimation results, Habsburg subsample

Dependent variable: Height in cm	Adults and youth		
	(11)	(12)	N
Troop category			
Light troops	-1.6	-2.2	44
Colonelle	3.4***	4.5***	492
Grenadiers	3.2**	2.1	71
Lieut. Colonelle	0.6	0.8	289
Infantry	Ref.		3,261
Age			
Ages 16 and 17	-6.7***	-9.2***	106
Age 18	-3.9***	-5.3***	171
Age 19	-2.0***	-2.7***	201
Age 20	-0.9	-1.2	316
Age 21	-0.2	-0.3	301
Age 22	0.0	0.1	338
Age 23	-0.4	-0.6	284
Age 24-50	Ref.		2,440

Table continues on the next page

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[133] We read off the values from: (p.60, figure 4: "Habsburg possessions, dummy regression"), so they should be considered approximations.

Table 8, continued

Dependent variable: Height in cm	Adults and youth		
	(11)	(12)	N
Birth cohort			
1656-1699	2.0***	2.8***	485
1700-1709	4.1***	5.5***	316
1710-1719	1.2**	1.7**	672
1720-1729	Ref.		1,298
1730-1739	2.3***	3.0***	412
1740-1749	3.9***	5.3***	386
1750-1754	4.9***	6.5***	225
1755-1762	3.3***	4.5***	363
Territory			
Bohemia	Ref.		1,113
Anterior Austria[134]	-0.4	-0.6	1,096
Silesia	-0.5	-0.6	558
Tyrol	1.6***	2.1***	331
Upper and Lower Austria	-1.1*	-1.5*	301
Unknown[135]	-0.3	-0.5	249
Moravia	-1.3*	-1.7*	217
Only Austrian Circle[136]	0.6	0.7	171
Southeast[137]	1.2	1.6	121
Enlistment circumstance			
Enlistment during war	-1.1***	-1.5***	1,975
Enlistment during peace	Ref.		2,182
Constant	166.7***	162.9***	-
Sigma	5.5***	constrained	-
Log-Likelihood	-6,020.8	-6,041.7	-
N			4,157

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In model (12), Sigma was constrained to 2.534 Fi (6.86 cm).

Komlos (1989) conducted a detailed study of heights in the 18th century Habsburg monarchy. He provided estimates for some of the territories[138] that are also part of our models 11 and 12. We do not consider it relevant to compare his estimates to our

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[134] Habsburg possessions intertwined with Swabia, but not part of the Swabian Circle.

[135] Contains observations where recruits could be born in one of the Habsburg possessions, but it is unclear whether the place of birth is located in the Austrian Circle or in Bohemia, Moravia or Silesia.

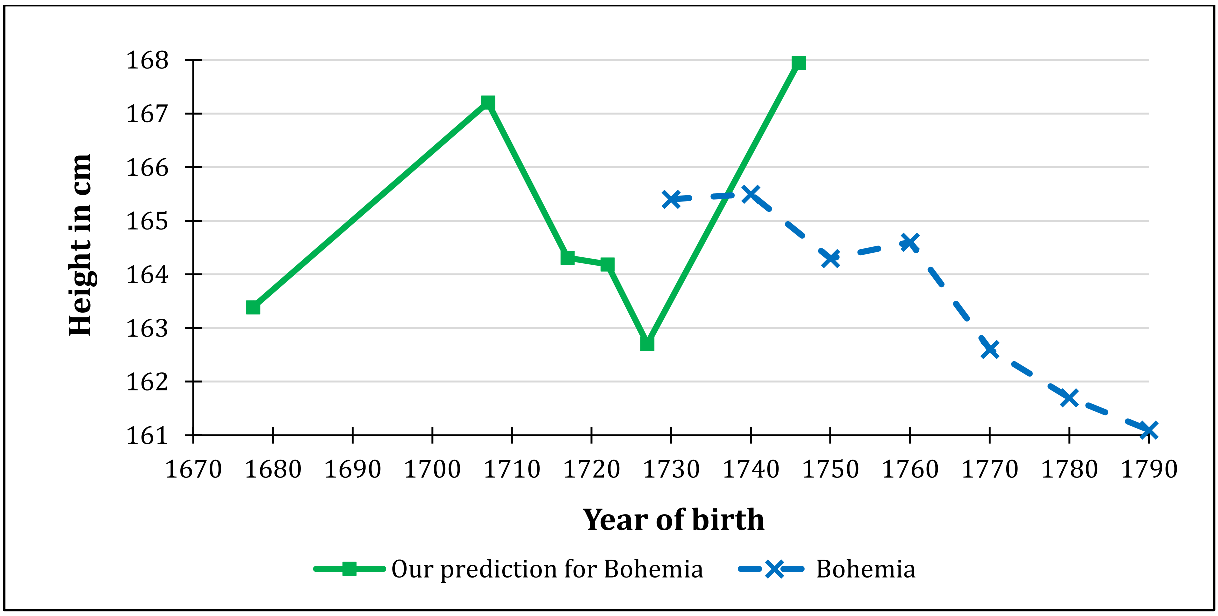
[136] Contains observations where it can only be determined that recruits were born in the Austrian Circle and recruits from territories with a small number of observations.

[137] Carinthia, Carniola and Styria.

[138] He also estimated average heights for regions of the Habsburg monarchy that are not included here since they were not part of the HRE, for example Hungary and Galicia.

estimates for the entire Habsburg possessions. Instead, we predicted[139] heights for Bohemia using a separate constrained regression. Our predictions for Bohemia deviate from Komlos' (1989) predictions. For the 1730s, we found Bohemians to be much shorter than what Komlos estimated. Afterwards, we estimated an increase in height, while Komlos predicted a decline (figure 17). Note that the final birth cohort we use in the regression ranges from 1730 to 1762 due to the low number of observations.

Figure 17: Predicted height of recruits born in Bohemia



Sources: See the text and a separate constrained regression for Bohemia. Bohemia: Komlos[140] (1989). *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

For Moravia (N=217) and Upper and Lower Austria (N=301), the sample size is too small to estimate trends, and comparisons with the trends estimated by Komlos (1989) are not feasible. In terms of mean heights of Moravians and Lower Austrians in our sample, Moravians are on average[141] 163.5 cm tall, as tall as soldiers born in Lower or Upper Austria who average[142] 163.6 cm. As far as the decades of birth in our sample overlap with the decades of birth in (Komlos 1989), the differences in estimated levels are substantial: The average[143] height of Moravians in (Komlos 1989) born in the decades between 1730

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[139] We do not have a sufficient number of observations to predict a trend for Moravia and Lower Austria.
[140] Values were copied from: (p.57, table 2.1, Adult soldiers, QBE estimates).
[141] Based on a constrained regression of height on a constant.
[142] Based on a constrained regression of height on a constant.
[143] Komlos (1989) calculated decade-specific averages (p.57, table 2.1). Our average is the unadjusted mean of theses averages.

and 1760 is 167.0 cm, and Lower Austrians in (Komlos 1989) born between 1740 and 1760 measure on average[144] 166.4 cm.

1.5.5. Territories on the frontier of the Empire and the Kingdom of France

In the Frontier Zone regressions, we used only two dummy variables as controls for territories within the Frontier Zone: One dummy was included for the Duchy of Lorraine and one dummy variable was used to single out all exclaves[145] of the Empire.

The Frontier Zone was no exception when it comes to the development of stature (figure 18): The trend follows a pattern that is analogous to the previously estimated trends, a small increase in stature in the last decade of the 17th century, a cyclical movement of decreasing and recovering heights, though, the decline in stature starting in the 1750s is most severe[146] here. Unconstrained and constrained estimates produce very similar results, with respect to the estimated coefficients and predicted heights, since the estimated standard deviation of the dependent variable is almost identical to the constrained value (table 9, model 13). Consequently, coefficients and predicted heights do not differ[147] substantially between the unconstrained and the constrained models Spline regressions with an automatically determined smoothing parameter did not yield convincing results for the Frontier Zone: The implied short-term variation in stature was too high compared to what is conventionally considered acceptable. Thus, we had to select the smoothing parameter manually[148] in this case. Alsatians were shorter than Lorrainians, and the difference is always statistically significant (table 9). The trend for the Frontier Zone is almost identical to our re-estimation of Komlos' (2003) trend for France (figure 18) after 1730. However, for the preceding decades of birth, we predict Alsatians and Lorrainians to be significantly taller than Frenchmen. Heyberger (2007) estimated trends in height for the whole entire as well as for a certain district in the center

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[144] Komlos (1989) calculated decade-specific averages (p.57, table 2.1). Our average is the unadjusted mean of theses averages.

[145] These exclaves are territories that never became permanently part of the Kingdom of France until the French revolution.

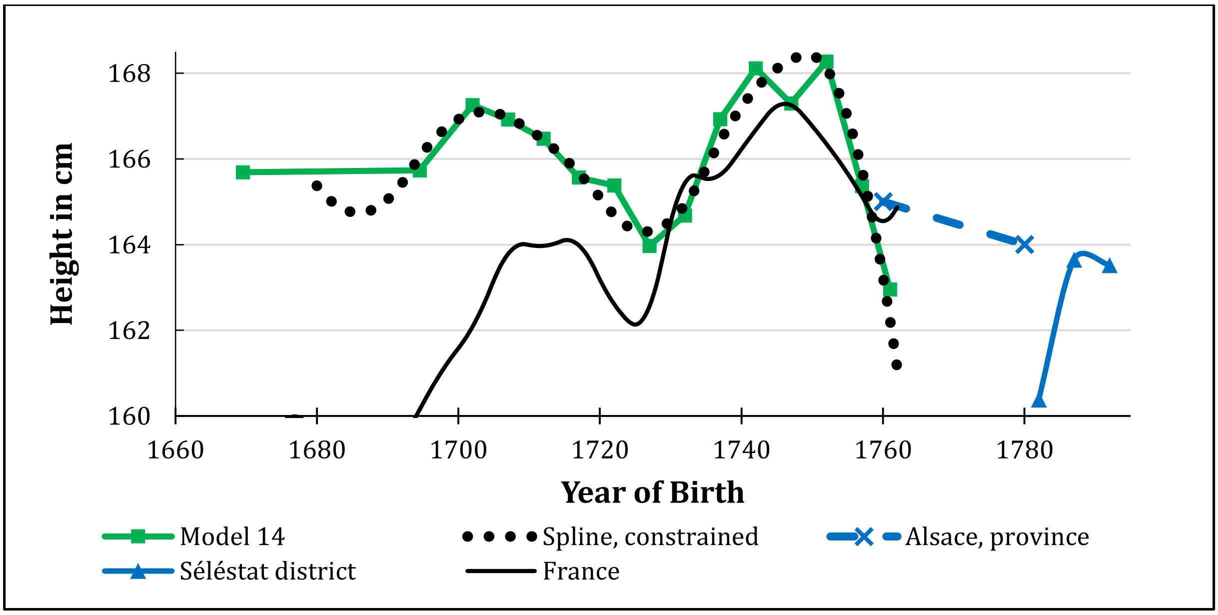
[146] In a latter subsection, we argue that population pressure is one driving force behind the decline in heights in the second half of the 18th century. We hypothesize that the steepness of the decline indicates that population pressure must have been severe in the Frontier Zone. The high population density in Alsace adds credibility to this hypothesis. The discussion of the determinants of the trends contains references for the statements we have just made.

[147] The average difference in predicted heights is 0.3 cm.

[148] We set the number of break points to 6.

of the Alsace but his estimates pertain to 20.5-year olds. We compared our trends to his trends for the Séléstat-district. Our final estimate for years of birth 1760-1762 is reasonable close to what Heyberger calculates for conscripts[149] (!) born in the second half of the 1780s if one assumes that decline in stature continued at a lesser rate. Heyberger's provincial estimates in 1760 are close to our constrained spline estimates[150]. Nonetheless, our predictions and his do not overlap further in terms of the birth decades studied, so we cannot draw a conclusion for the years 1763-1779. We estimated Lorrainians to be taller than Alsatians, as Komlos (2003). For the year 1745, he estimated Alsatians to be approximately 167.5 cm tall, and Lorrainians measured about 168.2 cm[151]. Our estimate of average height for this birth cohort is well matched to these values.

Figure 18: Predicted height of recruits born in the Frontier Zone



Sources: See the text and table 9; Séléstat district[152] and Alsace, province[153]: Heyberger (2007) France: re-estimation[154] of Komlos (2003). *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Spline regressions were restricted to years of birth after 1679.

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[149] Our findings (based on voluntary enlistment) and Heyberger's (2007) results (based on universal conscription) are not identical, but are in a common range of heights. We are convinced that this strengthens our argument that selection is not the driving force behind our results.

[150] We were unable to locate a detailed description of the provincial estimates in Heyberger's (2007) work, so we cannot elaborate on the similarity in stature between our study and his.

[151] We read off the values from Komlos (2003, p.173, figure 5), so they should be considered approximations.

[152] Values were copied from: (p. 238, table 3).

[153] We read off the values from: (p.239, figure 4: "Provincial Estimates"), so they should be considered approximations.

[154] Same method as described in footnote 88.

Table 9: Estimation results, Frontier Zone subsample

Dependent variable: Height in cm	Adults and youth		
	(13)	(14)	N
Troop category			
Light troops	-1.9***	-1.9***	699
Colonelle	5.5***	5.6***	2,183
Grenadiers	4.6***	4.6***	1,045
Lieut. Colonelle	0.6*	0.6*	1,804
Infantry	Ref.		20,215
Age			
Age 16	-6.6***	-6.7***	1,309
Age 17	-7.0***	-7.1***	2,801
Age 18	-5.3***	-5.5***	3,678
Age 19	-3.3***	-3.4***	3,113
Age 20	-2.6***	-2.7***	2,819
Age 21	-1.5***	-1.5***	1,828
Age 22	-2.1***	-2.1***	1,894
Age 23	-2.0***	-2.0***	1,424
Age 24-50	Ref.		7,080
Birth cohort			
1650-1689	0.3	0.3	214
1690-1699	0.3	0.4	540
1700-1704	1.8***	1.9***	665
1705-1709	1.5***	1.5***	755
1710-1714	1.1**	1.1**	1,092
1715-1719	0.2	0.2	1,676
1720-1724	Ref.		2,779
1725-1729	-1.4***	-1.4***	2,707
1730-1734	-0.7	-0.7	2,091
1735-1739	1.5***	1.5***	2,033
1740-1744	2.7***	2.7***	1,568
1745-1749	1.9***	1.9***	2,152
1750-1754	2.8***	2.9***	2,930
1755-1759	0.0	0.0	3,334
1760-1762	-2.4***	-2.4***	1,410

Table continues on the next page

Table 9, continued

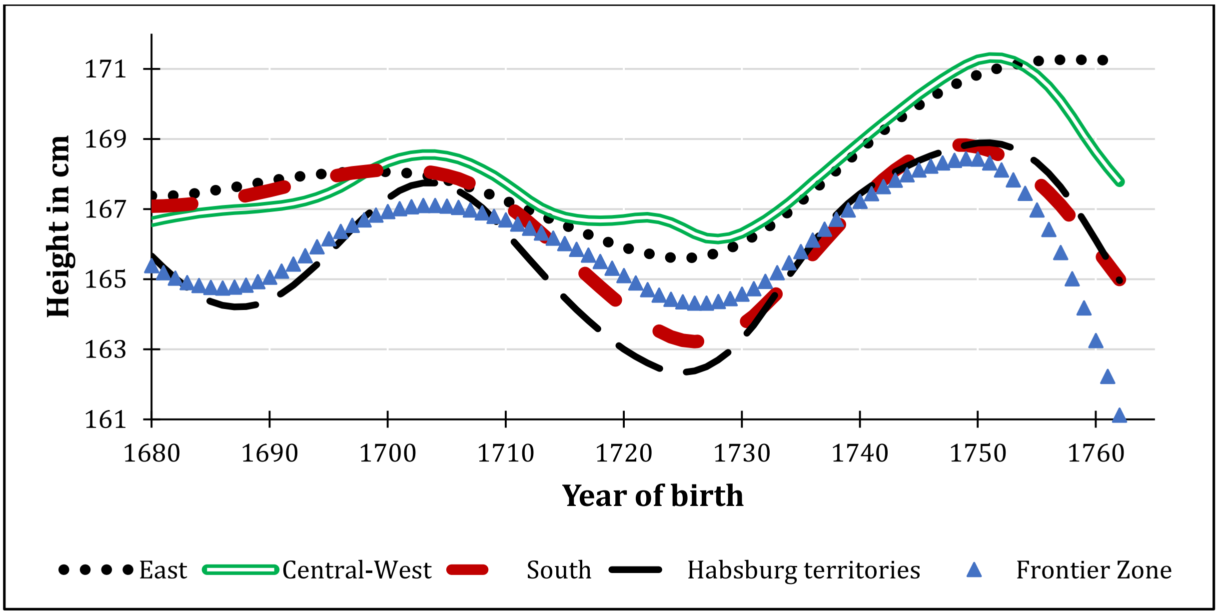
Dependent variable: Height in cm	Adults and youth		
	(13)	(14)	N
Territory			
Alsace	Ref.		15,401
Lorraine	1.2***	1.2***	9,837
Exclaves	0.9*	0.9*	708
Enlistment circumstance			
Enlistment during war	-1.3***	-1.3***	10,030
Enlistment during peace	Ref.		15,916
Constant	165.0***	164.7***	
Sigma	6.8***	constrained	
Log-Likelihood	-35,954.7	-35,955.1	
N			25,946

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In model (14), Sigma was constrained to 2.534 Fi (6.86 cm).

1.5.6. Summary of regional trends

The trends we estimate show some characteristics that are present in every region of the HRE (figure 19). Heights follow a cyclical pattern: They slightly increase from the second half of the 17th to the beginning of the 18th century in most regions, followed by a decline that ends in the 1720s. A subsequent recovery persists into the 1750s. Then, a deterioration of the nutritional status in all regions of the Empire - except the East - as well as in the Frontier Zone can be detected.

Figure 19: Regional trends in comparison



Sources: See the text and previously discussed constrained spline estimates of regional trends. *Notes:* The sample used in our calculations consisted of youth and adults.

The high correlation of the trends between regions that is visible in figure 21 becomes even more evident when correlations between the predictions for each region are calculated (table 10):

Table 10: Correlation of estimated regional trends

Region	East	Central-West	South	Habsburg territories	Frontier Zone
Central-West	0.88	1			
South	0.64	0.68	1		
Habsburg territories	0.80	0.91	0.84	1	
Frontier Zone	0.35	0.70	0.70	0.78	1

Sources: See the text. *Notes:* Correlations were calculated from the region-specific constrained spline regressions. Years of birth before 1680 were excluded from all calculations. Correlations were calculated using the predictions in cm. Notes: Results were rounded to two decimal places. All correlations are significant at least at 1%.

There are also differences between the regional trends other than the levels of heights: The decline is stature in the 1710s and 1720s was relatively mild in the East, but this was also the case in the Frontier Zone and in the Central-West region. In the South and the Habsburg territories, this decline was much more severe. This grouping of regions was not stable, however. The deterioration in nutritional status that started in the 1750s was most severe in the Frontier Zone. The Central-West, South and Habsburg territories also experienced a decline in height, but of less magnitude. Recruits born in the East were the only ones who did not experience a deterioration in the nutritional status (figure 19).

When the nutritional at the beginning of the 18th century was compared to the nutritional status in the 1760s, the pattern was also not uniform: Easterners born in the second half of the century were taller than their ancestors born in the first decade of the century. For soldiers from the Central-West, the first half of the 18th century was essentially a "zero-sum-game": Recruits born in 1760 attained a similar level of heights as did their ancestors born in 1700. Southerners, as well as for inhabitants of the Habsburg territories and the Frontier Zone, were markedly shorter in the 1760s than their predecessors born at the turn of the century had been.

Three corollaries can be drawn from the comparison of the regional trends: Firstly, the secular movements in height follow in general a common pattern in the entire Empire. Secondly, there is no convergence in terms of the levels, but rather a divergence: The biggest difference in heights was 1.4 cm[155] in 1705 and increased to 8.0 cm[156] in 1760. Additionally, the average difference in height was 0.6 cm in 1705 but 3.8 cm in 1760.

The general co-movement of all regional trends implies that a plausible explanation for the secular trend in heights must have been a phenomenon that had the power to affect all the regions at approximately the same time. This is fortunate for us, since it allows us to rule out specific causes that could have been of importance on a regional level, but did not affect the entire Empire. In the discussion about causes of the secular trends in the next chapter, the synchronicity of the regional trends is consequently used to exclude[157] certain factors as plausible explanations. These factors are also discussed in the following chapter.

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[155] Between heights in the Central-West and heights in the Frontier Zone.

[156] Between heights in the East and heights in the Frontier Zone.

[157] This does not imply that the causes we rule out do not influence stature on a regional level. We have documented a substantial variability of heights even within a given region, but it is beyond the scope of this study to offer explanations for these discoveries. This task is reserved for future work.

Chapter 2

2. Discussion of secular trends in stature in the Holy Roman Empire, ca. 1670 to 1760

In this chapter, we discuss the range of possible determinants of the nutritional status that can contribute to an explanation of our findings. We distinguish between causes of the secular trend and the determinants of the cross-sectional variation in stature. We then provide a short discussion of other determinants of height that can be *excluded* as reasons for the evolution of stature in our dataset. Also included is an account of determinants whose influences we cannot assess due to the limitations of our dataset or due to the lack of supplementary data. After a review of channels that have been discussed in the existing literature, we assess whether these mechanisms can also explain our results. As previously discussed, the synchronicity of trends between regions implies that "global" factors are the primary candidates as forces that explain the trajectory of the nutritional status.

Since height is determined by a multitude of influences[158], it is beyond the scope of this paper to attempt to discuss all possible causal links that could be at work in our data. Steckel summarizes: *"Adult height merely summarizes the final result, and if that's all that is available […] then researchers face a huge identification problem"* (Steckel 2009, p.8).

As a result, we limit our attention to plausible causes that have primarily[159] been discussed in the existing literature on 17th and 18th century European stature, focusing on channels proposed in the existing literature on the HRE and France. In most cases, the estimated trends are not attributed to a single cause. Usually, a variation in more than one determinant is proposed as an explanation.

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[158] See (Steckel 1995, 2009) for overviews. Komlos (1989) developed a model that illustrates the interdependencies between the nutritional status of a population and various economic and biological indicators. In his model, climatic conditions enter as an exogenous variable, whereas positive climatic conditions exert a positive influence on agricultural production, which in turn affects the nutritional status. Furthermore, Komlos argued that an improvement in the nutritional status of a population will correlate positively with population growth. Komlos' (1989) model also included food prices, which are influenced by the climate, and do influence fertility. He also described a wide array of possible channels through which fluctuations and cycles in height can be explained.

[159] This is to a certain degree the result of the availability of supplementary data.

2.1. Secular trends

In the existing literature, combinations of climatic conditions[160] and the relative price of nutrients, real wages and population growth (Komlos 1989, 2003, Baten 2002, Steckel 2005, Koch 2012) are the most probable explanations of secular trends in stature throughout the 17th and 18th century.

While changes in climate are obviously exogenous, the price of nutrients depends on the agricultural conditions and population growth: The decline in heights that began in the second half of the 18th century was interpreted as a sign of a Malthusian threat throughout Europe (Komlos[161] 1989, Komlos 2003, Heyberger 2007, Cinnirella 2008, Koch 2012, Komlos and Küchenhoff[162] 2012). Furthermore, fluctuations in harvest yields[163] had implications for the relative price of nutrients[164]. Komlos (1998) argued that population growth[165] in Europe had a negative influence on the nutritional status, since the amount of land suitable for farming could not be expanded rapidly enough. In most of Europe, there was not much space left to increase the amount of arable land (De Vries 1976). Komlos used the American colonies as a counter-example: In the colonies, *"[...] the land constraint was not binding"* (Komlos 1989, p.73), and thus, the colonists did not face a Malthusian threat[166]. However, Komlos argued that the *"Malthusian ceiling"* (Komlos 1993a, p.143) was ultimately broken due to progress that had been made in the economy. For early industrializing countries such as England, the onset of the Industrial Revolution

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[160] Primarily temperature and rainfall were discussed.

[161] Komlos (1989) attributed the decline in heights he estimated for the Habsburg monarchy as a sign of a Malthusian threat. Caloric intake as well as protein consumption declined.

[162] Komlos and Küchenhoff (2012) considered an increase in food prices combined with wages that did not keep pace with this development as the main explanation for the decline in English stature in the second half of the 18th century.

[163] The effect of the climate need not be confined to plant growth. Baten (2002) identified a second influence of climate on nutritional status: The size of the cattle stock, and consequently, the source of animal protein in the form of meat and milk, was dependent on winter temperatures, with higher winter temperatures and shorter periods of cold having a positive influence on the size of the cattle stock. Humidity in summer which correlated negatively with the quality of hay was another influence he identified.

[164] Food prices obviously affect the nutritional status if an individual faces budget constraints. However, in addition, the relative price of protein and carbohydrates can have substantial consequences for the nutritional status. Komlos (1998) described the mechanism at work: He explained that food became more expensive compared to other goods with the onset of the industrialization. He showed that this has two implications: Firstly, consumers altered the amount of food consumed. Secondly, the composition of the diet changed: Consumers increased their consumption of relatively inexpensive carbohydrates and reduced their consumption of relatively expensive meat.

[165] Komlos (1989) argued that there is also a reverse channel between the nutritional status and the population growth: An improved nutritional status can lead to population growth.

[166] In the European context, Komlos called the demographic expansion the *"original cause"* (Komlos 1993a, p.142) of the decline in the nutritional status.

alleviated the effects of population pressure to some extent, *"[…] the Industrial Revolution did at least allow the population to survive"* (Komlos 1993a, p.143), but just that. Fewer people died due to the increased demand for food, but survived in a malnourished state (Komlos 1993a).

2.1.1. Agricultural conditions

We commenced our analysis by exploring the relationship between harvest conditions and our estimates of height trends, as Abel (1974) argued that a starting point for an inquiry into the causes of hunger is the fluctuations of harvest yields[167].

Grain prices are a natural indicator of harvest conditions. For example, Komlos (2003) found a negative relationship between wheat prices[168] and the height of youth in France. Yet still, our results below imply that unambiguous conclusions about the biological standard of living cannot be drawn from the development of grain prices alone, given the data on grain prices we have at our disposal. We used a subset of data on real[169] rye prices created[170] by Robert C. Allen. We used the average[171] in rye prices from seven cities[172] located within our definition of the Empire. The price of rye is important as bread made out of rye was the staple diet in Europe at that time (Van Zanden 1999). Consumption of rye was more important than the consumption of wheat in Eastern and Central Europe (Van Zanden 1999), so we concentrate our attention to the price of rye. In particular, if grain prices are used to deflate nominal wages, a ceteris paribus increase in grain prices

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[167] Abel also believes that other aspects are important, among them the economic structure and society, urban-rural relations and landlord-subject relationships, as well as transportation structures (Abel 1974, p.189). However, none of these aspects could be analyzed by us given the available data.

[168] His grain prices were from Beauvais, France.

[169] All prices are in grams of silver per unit. These calculations were carried out by Robert C. Allen.

[170] The data was downloaded from: http://www.iisg.nl/hpw/allen.rar last access: 18.04.2017. We thank John Komlos for making us aware of this source. We also considered rye prices from the Allen-Unger Global Commodity Prices Dataset obtainable at the same source. We calculated an average price based on prices from all cities in the Empire in the second dataset. This average price correlates highly with the average price calculated by Robert C. Allen. The correlation is 0.83, significant at 1%. Consequently, we continued to use the data Robert C. Allen created. In part, these sources and in the Allen-Unger Global Commodity Prices Dataset could be identical, explaining the high correlation.

[171] All price series are significantly correlated, but with a varying intensity. The only exception is the price series from Vienna that does not correlate with the series from Antwerp. The correlations were calculated for the years 1655 to 1795. Missing values were ignored in calculations of the averages.

[172] Eight series of prices were used in the calculations, from the following cities: Antwerp, Augsburg, Gdansk, Leipzig, Munich, Strasbourg and Vienna, while the city of Munich contributed two series on rye prices. We excluded prices from Krakow which were available, although too fragmented. The series that contains the data for Krakow is highly correlated with the series we used (correlation coefficient 0.98, significant at 1%), so the omission is no reason for concern. The same is true if Gdansk is excluded, the resulting series correlates with the series we used with a correlation coefficient of 0.99, significant at 1%. The correlations were calculated for the years 1655 to 1795.

will lead to a decline in real wages. Van Zanden (1999) reported that grain[173] prices are important in determining the costs of living, since at least half of the available income was spent on bread made from wheat or rye. This of course, assumes that an individual faced a situation where foodstuffs are bought from the market. Kues extended the connection between harvests, grain prices and the nutritional status to self-sufficient farmers: *"[...] for self-sufficient farmers as well as for industrial workers, bad harvests and the subsequent high grain prices had a great negative impact on their nutritional status."* (Kues 2007, p.82). So, grain prices and the standard of living of peasants should be negatively correlated[174] even for farmers engaged in subsistence agriculture who do not sell their grain on the market.

Since, as Steckel phrases it, *"height at a particular age reflects an individual's history of net nutrition"* (Steckel 1995, p.1910), someone born in year *t* has a nutritional experience that is influenced not only by the economic situation at the time of birth, but also by the situation in the future. This is reflected in height due to the "cumulative" nature of the net nutritional status[175]. As a result, we calculated the average rye price for the first 16 years of an individual's life. That is, for every year of birth *t,* we calculated $\frac{1}{16}\sum_{i=t}^{t+15} p_i$where p_i is the rye price and t is the year of birth. The growth velocity of heights declines with age

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[173] He refers to wheat and rye.

[174] Yet, Abel (1966) provided evidence that grain prices may be positively related to a peasant's economic situation respectively his income: While Abel did not dismiss the assumption that bad harvests led to an increase in grain prices, he additionally argued that high grain prices need not necessarily be the result of a bad harvest: *"Nur in Deutschland und Österreich bogen die Preiskurven schon im letzten Viertel des 17. Jahrhunderts wieder nach oben um. Wie ein genaueres Studium der Preise zeigen würde, war dies zunächst durch Mißernten bedingt, doch setzte sich die Bewegung fort"* (Abel 1966, p.153), which casts some doubt on the suitability of prices as indicators of yields. In addition, he identified another consequence of depressed grain prices due to good harvests and consequently depressed grain prices: It became harder for a peasant to fulfil his obligation to the state and his landlord, in particular if contributions were demanded in terms of money and not in kind: *"Bei geringen Ernten hatten die Bauern wenig oder nichts zu verkaufen und mussten mit ihrer Familie hungern; bei guten Ernten sanken die Preise so tief, dass sie ihren Verpflichtungen gegenüber Staat und Grundherren nicht nachkommen konnten"* (Abel 1966, p.158). Abel made this statement with respect to French peasants. On another occasion (Abel 1966, p.149), he gave an example from the Empire, where a dispute over the payment of dues was discussed: The peasants asked for a payment in kind (that is to say, grain), but the landlord insisted on a payment in monetary terms since grain could be bought cheaper on the market. We cannot arrive at a definitive conclusion about the importance of this argument since we do not know whether the obligations had to be met in kind or in grain, and furthermore we do not know whether the quantities demanded also varied. Given the fragmented political structure of the Empire, it is very likely that this practice varied on a local level. However, note that a bad harvest necessarily had the same ramifications: If not enough grain is harvested due to low yields, not enough can be sold (even at high prices) to satisfy the landlord's demands (see Abel 1974, p.175 for an example). Furthermore, in times of high grain prices resulting from low yields, new grain to be sown the next year had to be bought at higher prices on the market (Abel 1974).

[175] We thank John Komlos for suggesting this specification with average of prices for a range of years after the year of birth.

until age 12. Then, growth accelerates again and peaks at age 14 for men. After the age of 14, the growth velocity rapidly declines (see Bogin 1999, p.69, figure 2.5). For this reason, we chose a 16-year average, so that for each individual, the prices of food he faced during the phase that is most influential for growth is accounted for. Throughout the discussion, we calculated correlations between explanatory variables and trends in height based on the constrained spline regression for the entire[176] Empire. The trends in stature are those depicted in figure 8 in chapter 1. We also discuss anecdotal evidence[177] on the incidence of subsistence crises from Abel (1966, 1974), as well as indications of subsistence crises based on a new dataset of real rye prices by (Albers et al. 2016). We also discuss the correlation of our trends to two climatic indicators, as they can reflect environmental conditions (Komlos 2003). Finally, we also discuss the correlation of stature and average real wages. Given this, we are convinced that the use of these additional variables strengthens our argument, since the use of climate data is not uncontroversial[178].

Throughout the entire era studied, heights and rye prices do not appear to be correlated[179]. This is implausible, but a visual inspection of both time series shows instances where the two series deviate from each other (figure 20), thus leading to an on average insignificant and weak correlation.

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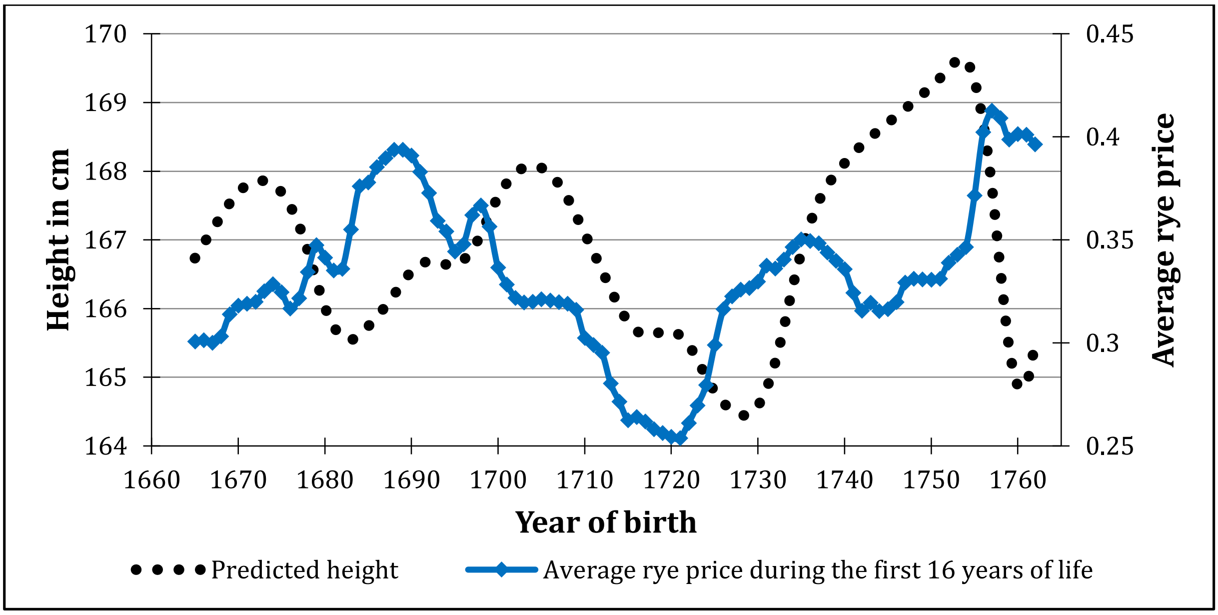
[176] This approach is feasible, since every regional trend is highly correlated with the trend for the entire Empire, with a correlation coefficient between 0.66 (East) and 0.92 (Habsburg territories). The correlations between every regional trend and the trend for the entire HRE are all significantly different from zero (Correlation coefficients were calculated based on the predicted heights from constrained spline regressions. Years of birth before 1680 were excluded).

[177] Abel (1966, 1974) often discussed crises in combination with citations from contemporary reports on harvests and prices, respectively the economic and social situation of peasants.

[178] Kelly and O Grada (2014) are critical of the application of smoothing techniques to climatic data. They argued that trends that are the result of a smoothing estimator that is applied to the data may not represent an actual trend, but are a spurious oscillation of the time series. They show that trends can even be produced from white noise.

[179] Correlation coefficient 0.07, p-value: 0.48.

Figure 20: Height and average rye prices.



Sources: See the text and chapter 1. Predicted height: Constrained spline regression depicted in figure 8. Rye price: Average rye price during the first 16 years of an individual's life based on prices by Robert C. Allen.

As a matter of fact, a more detailed discussion of the co-movement of both quantities is warranted: We can establish a significant negative correlation[180] between prices and height for a space of time from the second half of the 17th century to 1710. The magnitude of the correlation is in the same range as the correlation Komlos (2003) calculated for French heights and wheat prices in the first 50 years of the 18th century. The price pattern is broadly consistent with the anecdotal evidence: Average prices were high for those born around the subsistence crisis of the 1690s (Abel 1974), and those recruits born in the early 18th century enjoyed an improvement in nutritional the status that starts at the beginning of the 18th century is consistent with Abel's (1974) reports of good harvests and consequently low prices, lasting until circa 1707. For the years 1711 to 1719, both time series moved almost in parallel[181]. This is a puzzling result since Abel (1966) reported bad harvests and high prices for the years 1708 to circa 1710[182] which does not seem to be reflected in the 16-year price averages. Nevertheless, the nutritional status worsened in this period. The increase in the average of rye prices starting circa 1720, coincided with a continued decline in stature that lasted until 1730. Correspondingly, the correlation between both time series is highly negative at -0.98 and significant at 1%. This

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[180] Correlation coefficient: -0.63, significant at 1%.

[181] Correlation coefficient: 0.98, significant at 1%.

[182] Abel (1974) reported that the peaks of prices and the duration of elevated prices both varied between regions of the Empire. In the northern part, prices peaked around 1709, but remain elevated relative to 1707, towards the south and the east, prices peaked as late as 1712 or 1714.

result is again consistent with reports[183] of price hikes between 1722 and 1728 by Abel (1974). The opposite is true for the following five years (1731-1735): Heights and prices moved in the exactly the same direction[184]. After 1735, the correlation becomes again negative[185], supporting the conjecture that rye prices had a negative influence on the nutritional status. Abel (1974) reported a period of good harvests and low prices[186], reflected in the current upward trend in stature we estimated[187] and relatively constant average prices we calculated. In particular, the subsistence crisis of 1739-1741 (Abel 1974) did not lead to a cessation of the growth in stature, nor is it reflected in an elevated average price.

This finding is complementary to Baten's deduction[188] with respect to the relationship of real wages and stature: "*The downward deviation of real wages in the 1740s is known to be caused by the hunger years of 1740/41 that seems to have left no permanent mark on adult heights.*" (Baten 2000, p.68). Abel (1974) reported price hikes in England and parts of continental Europe around the middle of the 1750s, consistent with a turning point in our trend and a sharp increase in the average rye price. This increase can also in part be attributed to the crisis of the 1770s that Abel (1974) reported. These crises influence the nutritional status of an individual born in the late 1750s and the 1760s, since the cumulative nutritional experience is reflected in the average prices, and not only an isolated incidence of a subsistence crisis. The fact that we documented two time periods where rye prices were strongly positively correlated with stature can explain why we fail to identify an overall negative relationship between rye prices and stature. A second reason may be the fact that the discussion above does not consider a potential correlation of stature with other factors. This issue is addressed in the regression section, but first we have to assess whether additional variables contribute to a variation in stature. This strategy enables us to use the same approach as Komlos (2003), where correlations between time series are discussed before regression models are estimated.

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[183] His reports focused on France and parts of the Austrian Netherlands, but he also declared that corresponding high prices were also observed in Germany (Abel, 1974, p.177)

[184] Correlation coefficient: 0.96, significant at 1%.

[185] Correlation coefficient: -0.68, significant at 1%.

[186] *"Den Mißernten und Teuerungen der 20er Jahre folgte eine lange Reihe fruchtbarer Jahre und niedriger Getreidepreise"* Abel (1974, p.179).

[187] Baten (2000) also stated that climatic conditions were positive in the 1730s.

[188] Baten's refers to Austria and Bavaria.

Because the preceding discussion implies that given the data we have at our disposal, no 1:1 relationship between the nutritional status and rye prices can be established, we took the decision to use additional indicators of the economic and agricultural situation to further investigate the determinants of the nutritional status. Data on temperature and on rainfall for Central Europe is available, both of which are known to influence harvests (Baten 2002, Komlos 2003). The climatic variables may convey additional information on harvest conditions that may not manifest themselves in a variation of grain prices[189]. Finally, by choosing winter temperature and autumn rainfall, we ensured comparability of our results with the approach Komlos (2003) applied to explain his results. He used climate as a proxy of the environmental circumstances. However, neither do we expect the climatic indicators to be able to explain all variations in stature nor to be perfect proxies of harvest conditions, as harvests are influenced by a multitude of other factors.

We calculated the correlation between the predicted heights and Glaser's (2008) winter temperature[190] respectively autumn[191] rainfall data for Central Europe. As was the case with grain prices, we calculated correlations between predicted heights and averages of temperature respectively rainfall for the first 16 years of an individual's life.

Over the entire era covered in this paper, we do not find the expected[192]. positive correlation[193] between stature and Central European winter temperatures. As was the case with the series of heights and rye prices, spaces of time exist where both series move in opposite directions, but in other periods, the series clearly exhibit a co-movement (figure 21).

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[189] And conversely, grain prices may also be influenced by other factors than harvest conditions.

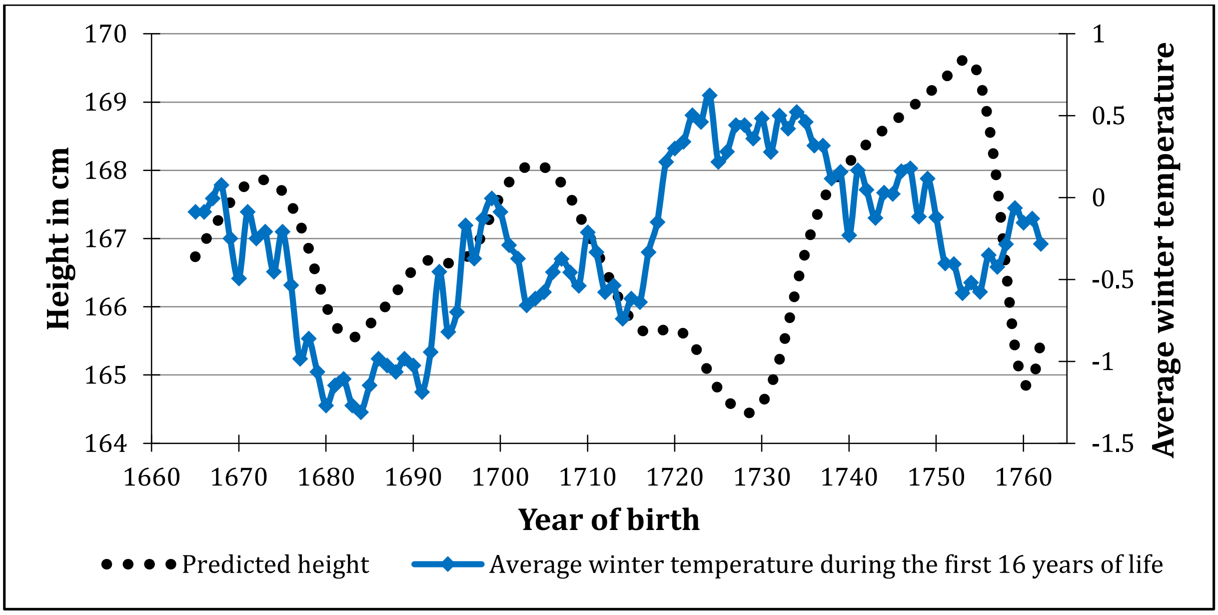
[190] Glaser's (2008) data also contains temperatures for the other seasons, but we concentrated our attention to winter temperatures.

[191] Glaser's (2008) data also contain rainfall for the other seasons, but we concentrated our attention to autumn rainfall.

[192] Komlos (2003) found a correlation between French heights and English annual temperatures of 0.52.

[193] Correlation coefficient: 0.09, p-value: 0.37.

Figure 21: Height and average winter temperatures



Sources: See the text and chapter 1. Predicted height: Constrained spline regression depicted in figure 8. Winter temperature: Average temperature during the first 16 years of an individual's life based on values from Glaser (2008).

The time series of heights and winter temperatures generally move in the same direction[194] until circa 1715 (figure 21). The relationship between the nutritional status and temperatures is then contrary to expectations throughout the remainder of first half of the18th century: The overall correlation is negative[195]. This can explain why we do not find a significant correlation for the entire space of time, as the different correlations may nullify each other on average[196].

The temperature data we used pertains to Central Europe. Glaser and Riemann[197] (2009) reconstructed[198] temperatures that are specific to Germany. Their temperature series exhibited a pattern that is more consistent with the estimated trend in stature, in particular the recovery in heights between the 1720s and the 1750s and the following sharp decline correspond to a space of time where winter temperatures in Germany first

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[194] Correlation coefficient: 0.67, significant at 1%.

[195] Correlation coefficient: -0.53, significant at 1%.

[196] It should be noted that the correlations we derived may be dependent on the type of smoothing technique used. If the temperature data is instead smoothed using a spline smoother, we obtained results that are more in line with expectations, but we consider a unified treatment where every possible explanatory variable is treated in the same manner as more appropriate. It is beyond the scope of the work to consider model selection.

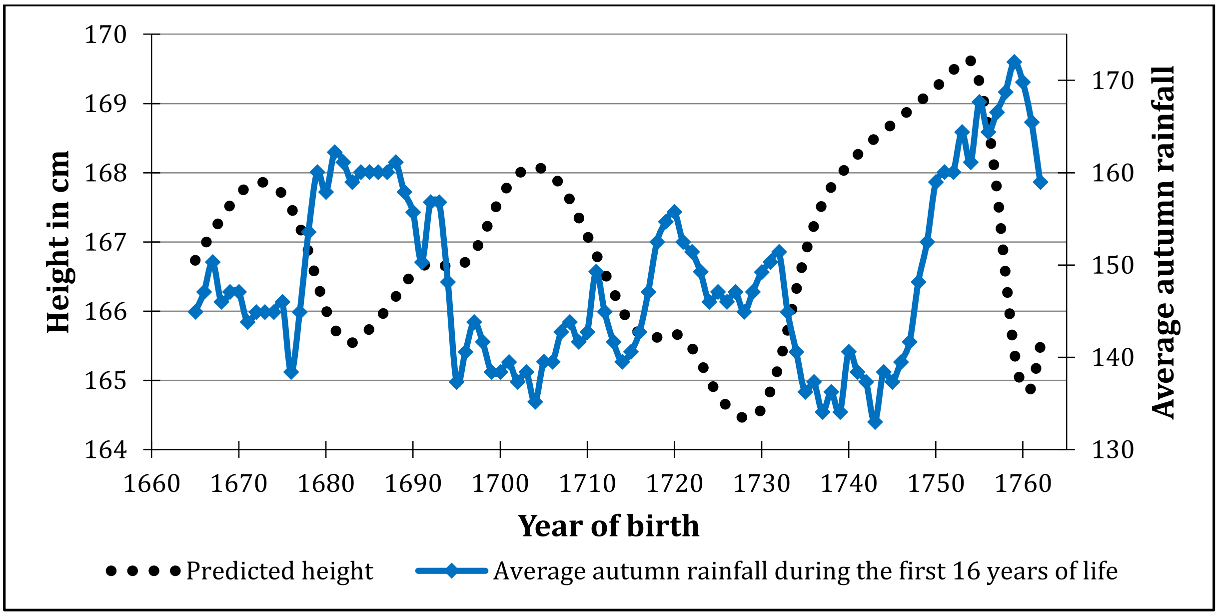
[197] We thank John Komlos for bringing our attention to this article.

[198] Depending on the era studied, the reconstructions are either based on documentary or instrumental evidence (Glaser and Riemann 2009). In the following description, we refer to Glaser and Riemann (2009, p. 447, figure 8,).

increased and remained on a comparatively high level, only to decline again after their maximum was reached in the 1750s continuing on to the turn of the century.

Too much autumn rainfall exerts a negative influence on harvests (Komlos 2003). Therefore, a negative relationship between the amount of rainfall in Central Europe and the nutritional status can be expected. Does the use of this second climatic indicator of harvest conditions (figure 22) lead to conclusions that are consistent with the implications drawn using the temperature data? The answer is clearly yes; the rainfall data complement the temperature data.

Figure 22: Height and autumn rainfall



Sources: See the text and chapter 1. Predicted height: Constrained spline regression depicted in figure 8. Autumn rainfall: Average autumn rainfall during the first 16 years of an individual's life based on values from Glaser (2008).

Autumn rainfall and stature were negatively[199] related over the entire time period under consideration. The fact that the estimated correlation is not higher can be explained by a single time period where strong positive correlation between both time series increase the overall correlation (thus, the correlations is less negative). Until 1740, the correlation is -0.50 (significant at 1%), but between 1740 and 1749 the correlation is positive at 0.67 (significant at 5%). Afterwards, we again find a negative correlation[200]. Hence, the results using the second climatic indicator support the conclusions drawn using winter

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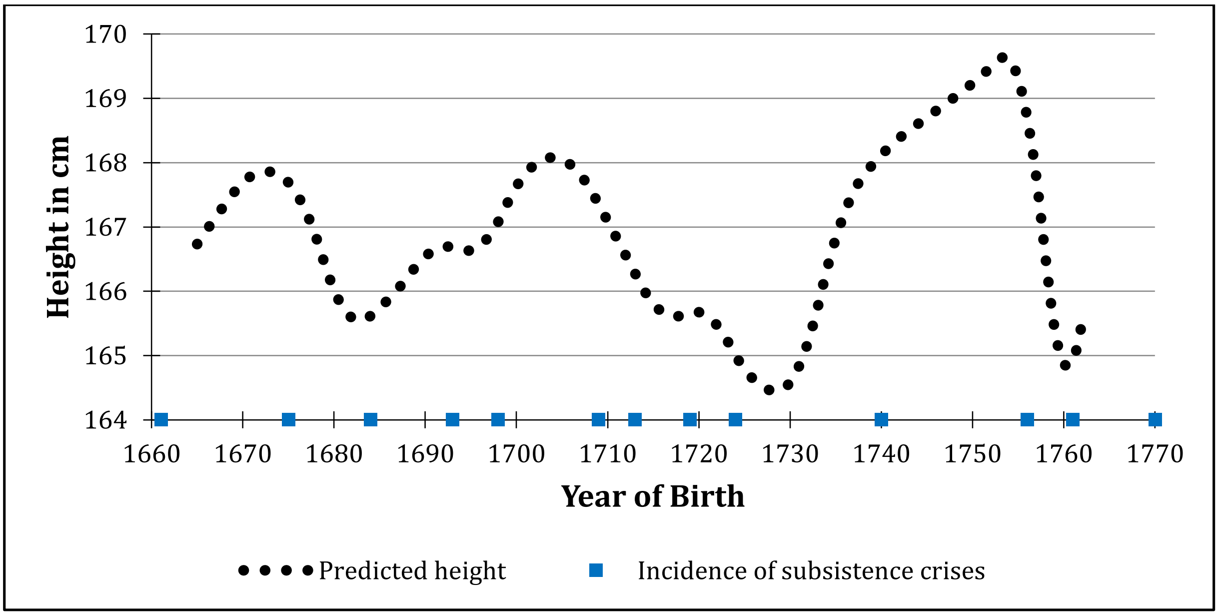
[199] Correlation coefficient: -0.21, significant at 5%.

[200] Correlation coefficient: -0.51, significant at 10%.

temperatures, and provide additional evidence that harvest conditions contribute to the explanation of the trends in height.

A third indicator of harvest conditions is available: Albers et al. (2016) currently create a new dataset on rye prices. They define a subsistence[201] crisis in terms of a price peak in real rye prices. In most instances, the incidences of subsistence crises are very similar to the occurrences of crises that were discussed in Abel (1966, 1974). In most cases, the level and development of our secular trend is consistent with the incidence and "frequency[202]" of subsistence crises (figure 23), however, we cannot gauge on the severity of the respective crises.

Figure 23: Height and subsistence crises



Sources: See the text and chapter 1. Predicted height: Constrained spline regression depicted in figure 8. Incidences of subsistence crises are taken from Albers et al. (2016, p.26, figure 4). Albers et al. (2016) reported subsistence crises also in 1750 and 1795, which are not included in the figure above.

Heights began at a low level after the crises in 1650 and 1661, increased in the subsequent crisis-free period only to decline again during the crisis of 1675. A new low in stature corresponds to the crisis of 1684. To the contrary, the next two crises did not manifest themselves in declining heights, but in the growth rate of stature which is reduced to zero. The continued decline in stature in the 1710s and 1720s and the new low of heights

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[201] Pfister and Fertig (2010) used another definition of subsistence crisis in terms of birth and death rates. Although not completely identical, their conclusions about the incidence of subsistence crises are similar to the results from Albers et al. (2016). Pfister and Fertig identified subsistence crises in the following years, respective time spans: 1689 to 1694, 1710/1712, 1718/1721, 1727 (only in the north-west), 1740, 1758, 1762/1763, 1772 and 1795. See (Pfister and Fertig 2010, p.32-33) for details.

[202] By "frequency" we mean the number of subsistence crises that occur in a given time frame.

attained in the late 1720s corresponds quite well[203] to a decade of four consecutive crises in a short period of time. The crisis around 1740 is not reflected in the nutritional status. of those born at the time, but we hypothesize that it could have contributed to the low in stature attained some 10 years earlier[204]. The crisis of 1756 coincides almost perfectly with a change in the trajectory of the estimated trend.

This third indicator of food availability further supports the hypothesis that the nutritional status of the population of the HRE was susceptible to negative variations in food availability.

Real wages are a complementary[205], - but of course related to grain prices- indicator that is commonly studied in combination with secular trends in stature. The relationship between height and real wages is documented in the existing literature (for example, in Koch 2012 and Baten 2000). In Baten's (2000) overview article, he combined time series in stature with time series in real wages. His analysis pertaining to the 18th century began with the decade of the 1750s and ended in the 1790s. Baten ascertains that real wages and heights are positively correlated in this epoch.

We utilized data on real day wages[206] of unskilled urban male laborers calculated by Pfister (2017), confirming the pattern we found using the grain prices and climatic indicators[207]. However; the overall correlations between average real wage for the first 16 years of an individual's life and heights appears to be negative[208]. A calculation for the

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[203] The actual low in stature follows slightly after the period of multiple crises, but this need not be reason for concern: Baten used the decline in stature in the second half of the 18th century as an example to illustrate this point: *"In order to determine whether there was a decline in height in the late 18th century, for example, it is relatively unimportant to know exactly whether this decline started in 1746 or 1748."* Baten (2000, p.63). Baten made this statement under the restriction that long- term trends must be studied.

[204] That is, to say, the growth of adolescents born in the late 1720s or early 1730s might have been influenced by this crisis if it fit hit them during the adolescent growth spurt and contributed to their low average stature.

[205] As previously discussed, the real wage may be a particularly useful indicator because it captures the effect of food availability for those subgroups of the population who were most exposed to market forces (Komlos 1989, Baten 2000).

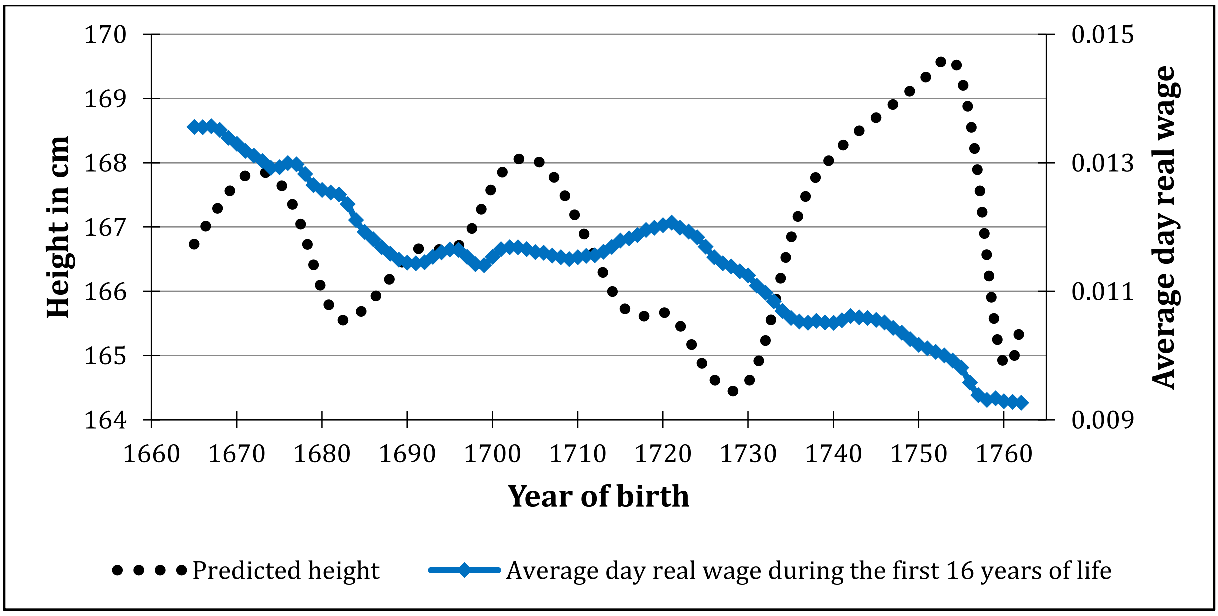
[206] Our calculations are based on the following source that accompanies Pfister (2017): "annual values of day wage divided by CPI, scaled to average of eight towns in 1773–77, with interpolations for missing years". The data was downloaded from: http://onlinelibrary.wiley.com/store/10.1111/ehr.12419/asset/supinfo/ehr12419-sup-0003-Appendix3.xlsx?v=1&s=f7f06ea52baecea65212d90ac429b49f38a19ac6 last access: 27.3.2017.

[207] This is to a certain degree not surprising: If climatic conditions reflect harvest yields, increases in grain prices will of course also have ceteris paribus consequences for real wages, since the grain price will correlate with the price of foodstuffs, in particular bread. Note that the real wage estimates by Pfister (2017) include, but are not limited to bread.

[208] Correlation coefficient: -0.20, significant at 5%. However, we do not consider this strategy to be sensible. While it is evident from figure 24 that the real wage continuously declines from the second half of the 17th to the second half of the 18th century, the pattern in stature is more dynamic. Consequently, a correlation

entire time period is probably driven by the long-term negative trend in real wages and the steep increase in stature from the 1730s to the 1750s, thus yielding an overall negative correlation (figure 24). To allow for more short-term flexibility in the relationship between the two series, we calculated the correlations for three sub-periods: In the second half of the 17th century, we found the expected positive association[209] between day real wages and heights. From 1700 to 1734, there is no detectable correlation[210] between both quantities. This finding very much resembles Baten's observation in respect to 18th century Austria: *"During the two decades before mid-century the series*[211] *do not move together, however."* (Baten 2000, p.68). Afterwards, the correlation is again of a magnitude similar[212] to the one in the 17th century. Real wages remained low in the second half of the 18th century. So, an individual born in this era did not grow up in an environment where an increase in purchasing power could have led to improvements in the nutritional status.

Figure 24: Height and real wages



Sources: See the text and chapter 1. Predicted height: Constrained spline regression depicted in figure 8. Day real wage: Average day real wage for the first 16 years of an individual's life based on values from Pfister (2017).

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over a time period of more than 100 years is not very meaningful. In addition, if the cycles in height are not taken into account, but the levels of height in 1700 and 1760 are compared, the trends in real wages and in stature are compatible. Real wages were higher in 1700 than in 1760, and people were taller in 1700 than in 1760.

[209] Correlation coefficient: 0.47, significant at 1%.

[210] Correlation coefficient: 0.08, p-value: 0.64.

[211] By both series he means height and real wages (our footnote).

[212] Correlation coefficient: 0.54, significant at 1%.

The preceding discussion implies that real wages are not a perfect predictor of the trends in stature. Yet, this result does not pose any problems, since the susceptibility of heights towards fluctuations of food prices or real wages depends on the exposure of individuals to market prices. For the Habsburg Empire, Komlos summarized: *"Because in the middle of the 18th century, large segments of the Habsburg population were isolated from the market, one should not expect market prices of food to correlate perfectly with fluctuations in stature. […] Yet, aside from minor deviations, the downward trend in stature during the second half of the 18th century is in general agreement with the negative trend in the purchasing power of daily wages"* (Komlos 1989, p.105-106). Baten drew a similar conclusion: *"The more dependent a regional population was on buying food in the market, the higher was the elasticity of their heights with respect to real wages"* (Baten 2000, p.66).

To summarize, the relationship between real wages and the nutritional status we document for the HRE is in line with Baten's reasoning. *"In sum, real wages and heights in the 18th century are characterized by very similar general trends"* (Baten 2000, p.70). However, no time series Baten (2000) considers began before 1730. We contribute by establishing the expected positive relationship between real wages and stature for the second half of the 17th century, but we cannot add evidence that heights and real wages correlated before the 1730s. The relationship between heights and real wages we found corroborates our inference using the climatic indicators and grain prices, and make up for the fact that one indicator alone may not be able to explain the secular trends.

2.1.2. Population growth

How does population growth contribute to the explanation of these trends? As mentioned in the introduction, population growth and a possible Malthusian threat is another likely candidate as an additional explanatory variable, in particular in the second half of the 18th century.

A detailed population history of the Empire is still subject of ongoing research. We used information provided in (Pfister and Fertig 2010) as our primary source. Since they constructed a population history of Germany[213], the territorial concept they used is

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[213] Note that Pfister and Fertig constructed a series on the aggregate level of Germany, as best as the then available data allowed. In the section where we explain the cross sectional variation in stature, we used a different source that depicts the distribution population across the Imperial Circles at the end of the 18th century but does unfortunately not provide estimates of population growth.

different[214] from ours, and we supplemented their figures with other sources, in particular regional statistics where we considered it to be necessary. In the following discussion, we use the term "Germany" to refer to the definition of the Empire used by Pfister and Fertig (2010).

Pfister and Fertig (2010) estimated the population size of Germany for the years before 1730. Their results showed a steady increase[215] in population after 1650, when the population started to recover from the population losses of the Thirty-Years' War. These results are similar to other research[216] that also shows a steady increase[217] in population from the 1650s on. Pfister and Fertig (2010) found a steep increase in population from 1650 to 1660. Afterwards, depending on the definitions[218] used, their results either showed two phases of linear[219] population growth, one lasting from 1660 to 1690, and a subsequent phase of linear growth with a steeper positive slope, or a growth trajectory that is linear from 1650 to 1750 without any change in the slope. According to the estimates, the population size again reached the same level in the 1730s as it previously had in the 1620s[220]. We interpret their findings -notwithstanding the skepticism that Pfister and Fertig (2010) themselves show towards their own results[221]- as support of our estimate of secular trends in height from the 1660s to the 1730s. The population recovered from the losses of the Thirty-Years' War, but not shocks to population size, neither negative nor positive, were evident. Since there were no exceptional phases in the development of the population, it is unlikely that the variation in stature was driven by

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[214] Pfister and Fertig's definition of the Empire excludes the Habsburg possessions (but includes Anterior Austria). The Habsburg territories in what is today Belgium are also excluded (see Pfister and Fertig 2010, p.4-5 for a detailed description of their definitions.)

[215] Our statement refers to: (Pfister and Fertig, 2010, p.12, figure 1). The values that Pfister and Fertig depict in the figure are for 10-year intervals based on their own research.

[216] See (Pfister and Fertig, 2010, p.5, table 1) for details.

[217] Our statement refers to: (Pfister and Fertig, 2010, p.12, figure 1). The values that Pfister and Fertig depict in the figure are for 50-year intervals (1650, 1700, 1750) based previous own research.

[218] The trajectory depends on whether Prussian territories are excluded or not.

[219] Pfister and Fertig (2010) do not use this term. From our visual inspection of (Pfister and Fertig, 2010, p.12, figure 1) we concluded that the population growth over time resembles a straight line, therefore the term "linear".

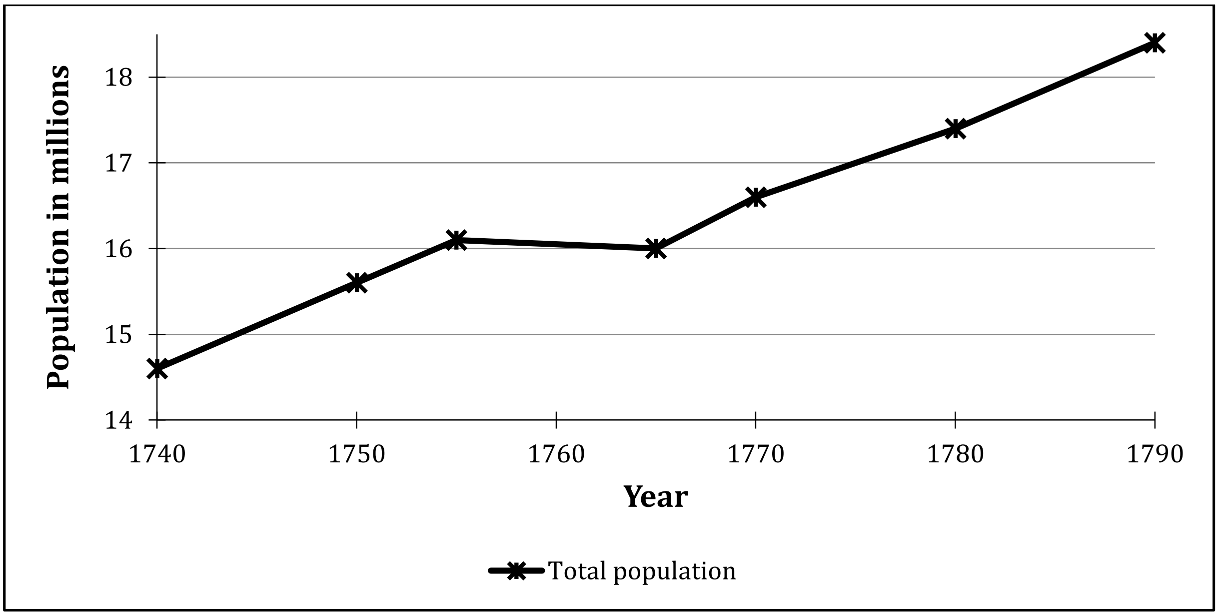
[220] The effects of the Thirty Years' War are visible in the figure that Pfister and Fertig (2010) depict on page 12: Population decreased from 14 million in the 1620s to around 6 million in the 1650s. The other estimates that they also depict in the same figure imply a decline in total population from around 13 million to 8 million due to the war (We read off the values from p.12, figure 1, so they should be considered approximations.).

[221] Pfister and Fertig (2010) included a disclaimer stating that their results are preliminary and that not too much importance should be attributed to them, though they reveal that their estimates do not contradict previous research (Pfister and Fertig, 2010, p.13). They added this disclaimer since population growth varied greatly on a regional level.

the change in total population, and the previously discussed agricultural conditions are still the most plausible causes of the development in nutritional status in the first quarter of the 18th century.

Pfister and Fertig (2010) also provided new estimates[222] of the total population in Germany after the 1730s. Again the representation is one of a steady increase in the total population, without any exceptional periods[223] (figure 25).

Figure 25: Total population in Germany, 1740 to 1790



Sources: Values from: (Pfister and Fertig 2010, p.5, table 1, column 3).

However, Pfister and Fertig (2010) made a statement with respect to the birth- and death rates after 1730 that implied an increase in the population pressure: They find an *"early and hesitant stage of the secular decline in mortality, whose beginnings can tentatively be located in the 1740s"* (Pfister and Fertig, 2010, p. 30). Furthermore, they concluded that the birth rate was higher than the death rate most of the time[224], consequently, population

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[222] Pfister and Fertig (2010) also calculated crude birth and death rates starting in the 1690s. Unfortunately, they argue that their birth rate and death rate estimates before the 1730s should not be used since there are discrepancies to other estimates (Pfister and Fertig, 2010, p.30).

[223] Abel (1974) also mentioned that population growth increased in the second half of the 18th century in Germany.

[224] Pfister and Fertig nevertheless reported that these periods of excess births over deaths were still interrupted by hikes in the death rate, which became equal to or even surpassed the birth rate in some spaces of time. In (Pfister and Fertig, 2010, figure 4, p.31), such periods are visible around 1740, 1750, and approximately during the Seven Year's War (1756 to 1763). Another hike in death rates is visible around 1771 and 1773. In addition, Pfister and Fertig (2010) argued that the birth rate remained almost constant for a hundred years after 1740. The death rate also remained approximately constant, except for the previously mentioned hikes, until the 1820s.

growth must have accelerated. This is also reflected in the increase[225] in the dependency ratio[226] that started in the 1760s. The authors reported: *"We see clearly a rise in the dependency ratio between c. 1760 and 1830. This was primarily a consequence of the growing number of children relative to adults, which in turn resulted from the acceleration of population growth following the onset of the mortality decline around the middle of the eighteenth century"* (Pfister and Fertig, 2010, p.37). Pfister and Fertig made a second statement related to this finding which almost perfectly describes why the nutritional status must have worsened in the second half of the 18th century: *"The real wage did not move in the same direction as the dependency ratio. From a householder's perspective, in the late eighteenth century more mouths had to be fed from a declining income. Thus, household incomes per capita probably declined more rapidly than the real wage among the labouring classes during this period."* (Pfister and Fertig, 2010, p.37).

Pfister and Fertig (2010) themselves and, building on their results, Fertig and Pfister (2014) conclude[227] that Germany was in what they called a "high pressure" Malthusian situation[228] from 1730 on[229]. The onset of a decline in stature we estimated for the second half of the 18th century is consistent with an increase in Malthusian pressure.

Komlos (1990b) described the prerequisites for a Malthusian crisis[230]: Continued or accelerated population growth, and an agricultural output that cannot keep pace with this development. As the discussion of the grain prices and climatic variables suggested, we have no reason to believe that agricultural output experienced a phase of continuously exceptionally good harvests after the 1730s, and Pfister's and Fertig's previously mentioned arguments show that population pressure must have increased.

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[225] Note that a drop in the dependency ratio from the 1740s to the 1760s happened beforehand. We hypothesize that this could to some extend explain why heights started to diminish around 1755 and not earlier Note that Pfister and Fertig (2010) only showed the dependency ratio from 1740 on.

[226] Pfister and Fertig defined the dependency ratio as: *"[…] the ratio of non-working age to working age persons […]"* (Pfister and Fertig, 2010, p.37).

[227] The paper by Fertig and Pfister (2014) is closely related to Pfister and Fertig (2010) in the sense that it overlaps to some extent with respect to the issues discussed in the latter.

[228] Pfister and Fertig (2010) defined a "high pressure" Malthusian situation as follows: The positive relationship between real wages and the birth rate is rather weak, while the negative relationship between real wages and death rates is rather strong.

[229] This does not imply that Germany was not subject to the general Malthusian dynamics in the time before 1730. Rather, the data on birth rates and death rates before 1730 that Pfister and Fertig (2010) have at their disposal is not reliable in their opinion.

[230] Komlos used England as an example where the high level of economic development helped to avert such a crisis.

The demographic trends in regions of the Empire that are not part of Pfister and Fertig's (2010) definition of Germany are very similar: Klep (1991) estimated the total population of today's Belgium by region and in 50 year intervals[231]. Klep (1991, p.486) distinguished three regions: Brabant, Flanders and what he calls "Rest (sic)[232]". The number of inhabitants grew to some extent from 1650 to 1700 in all regions. From 1700 to 1750, population growth continued in Flanders, while it virtually stagnated in Brabant and "Rest". In the years 1750 to 1800, population growth continued in Flanders and greatly accelerated in Brabant and "Rest". Bardet and Dupâquier (1997) confirmed this pattern. They find that the population in Brabant grew only by 4% between 1709 and 1755, and in the thirty years that followed, the population[233] grew by 27% in Brabant and 30% in Flanders[234].

The picture is essentially the same for the Habsburg possessions in the southern part of the Empire and for Bohemia, Moravia as well as Silesia (Bardet and Dupâquier 1997, 1998). Total population grew steadily in Austria[235] from 2.1 million in 1700[236] to 2.8 million in 1780[237]. In Bohemia and Moravia, the pattern[238] of growth is related to the one described for the Spanish/Austrian Netherlands except Flanders: Pronounced growth from the second half of the 17th century to 1700 was followed by an almost constant total population until growth increased in the second half of the 18th century. We did not have population figures for Silesia in the 17th century at our disposal, but Silesia was no exception when it came to the growth in the number of inhabitants in the 18th century:

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[231] Our following description of the growth in total population is based on the values from: (Klep, 1991, p.486, table 1).

[232] "Rest" contains the provinces Hainaut, Namur, Liège, Belgian Limbourg and Belgian Luxembourg. Klep (1991) calculated the total population for each of the three regions separately. All regional definitions do not completely overlap with the Spanish/Austrian Netherlands, so the population figures should be considered as approximate indications of the population growth in the Spanish/Austrian Netherlands.

[233] Bardet and Dupâquier (1997) noted that when military troops marched through these territories during wars, this was still very burdensome for the population, but the demographic consequences were less severe now compared to previous centuries.

[234] Bardet and Dupâquier (1997) did not make a statement with respect to population growth in Flanders in the period of 1709 to 1755.

[235] Note that Bardet and Dupâquier (1997) include Salzburg, which was at that time part of the HRE but not part of the Austrian Circle.

[236] Value for 1700: (Bardet and Dupâquier 1997).

[237] Value for 1780: (Bardet and Dupâquier 1998).

[238] This description is based on the following population figures: For 1650 to 1750: (Bardet and Dupâquier 1997, p.542, tableau 90. For 1780: (Bardet and Dupâquier 1998).

Population estimates[239] for 1700, 1740, and 1800 indicated slow growth before the 1750s, and strong growth afterwards (Bardet and Dupâquier 1998).

Demand for food obviously increased with the continued growth in population, resulting in increasing prices of foods and falling real wages due to a decreasing marginal product of labor in agriculture.

We are not the first researchers to draw this conclusion with respect the Empire. To some extent, Koch (2012) attributes the secular trends he estimated to the development of real wages, and he connects this development to the population growth. Komlos and Heintel (1999) confirmed the pattern of falling real wages and population growth for the Habsburg monarchy.

To summarize, the late 17th and the 18th century did not generate persistent improvements in the nutritional status of the population of the HRE. Any amelioration of the nutritional status was, even under the most ideal conditions, only of brief duration, and the living conditions unambiguously worsened in the second half of the 18th century. The population remained susceptible to fluctuations in agricultural conditions throughout the late 17th and the first half of the 18th century. The sharp decline in heights in the second half of the 18th century points to the threat of a Malthusian crisis, when the continued or even accelerating population growth began to take its toll, as it was not accompanied by a corresponding increase in agricultural productivity.

2.1.3. Regression results

The preceding discussion provided evidence that no single factor alone can sufficiently explain the secular trends we estimated Therefore, we made the decision to use regression analysis to explore the relationship between heights and their determinants in more detail.

We began with a regression specification where the estimated height served as the dependent variable:

$$\widehat{height}_t = \boldsymbol{x_t}\boldsymbol{\beta} + u_t$$

where:

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[239] All population figures: Bardet and Dupâquier (1998, p.399, tableau: "Évolution de la population dans quelques régions".)

- $\widehat{height}_t$ is the predicted height for year of birth t based on the constrained spline regression depicted in figure 8 in chapter 1
- $\boldsymbol{x_t}$ are the explanatory variables discussed in the preceding sections
- u_t is the error term

The coefficients $\boldsymbol{\beta}$ are then estimated by OLS.

For ease of interpretation, we rescaled some of the variables used in the regressions: Population is measured[240] in millions. The real wage is measured in grams of silver per year (day real wage by multiplied by 365). Due to the cumulative nature of the nutritional status, we used again the average of the respective variables for the first 16 years of an individual's life in the regressions.

As was the case with the partial correlations we considered up to this point, we could not establish a relationship between the nutritional status and the suggested determinants that is stable over the whole time period we study. A regression that contained averages for the first 16 years of life for each of the variables rye price, winter temperature, autumn rainfall, total population, and real wages did not yield convincing results. In particular, the effect of rye prices and temperature were contrary to what would be expected[241]. With the exception of winter temperature and rainfall which both had a negative influence and were significant, rye prices, real wages and total population were insignificant, but the estimated coefficients were all positive and insignificant[242] (results not shown).

Because the regressions for the entire time period did not yield consistent results and imposed that the effect of a determinant would have to be constant for approximately a 100-year period, we considered it more prudent to estimate regressions for two sub-

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[240] Population figures for the Empire are not available on a yearly basis to the best of our knowledge. We made use of the same population figures as previously discussed and linearly interpolated the values for years without measurement and added up the values. This yielded a total population of approximately 28.2 million for the entire Empire in 1790. This is well-matched to Hartmann's (1995) estimate of 27.5 million individuals in 1795. A more accurate estimate of the total population for the entire Empire was not at our disposal. We assumed that the population was constant at the level of 1650 for the years 1644 to 1649 since we did not have other data.

[241] The same was true if we followed Komlos' (2003) strategy and regressed a 5-year lag of either adult or youth heights on 5-year moving averages.

[242] Robust standard errors were used. Bootstrapped standard errors with 100 replications did not change the significances. The results were robust to the inclusion of a dummy for subsistence crises based on the crises defined in (Albers et. al. 2016). When rye prices were omitted from the regression, real wages had a negative and insignificant effect, and when real wages were omitted instead, population became significant but a rye prices still had a positive coefficient Rye prices retained a positive influence if population was omitted, too (results are available upon request).

periods, since, as previously discussed, the relationship between the variables we considered and stature does not seem to be constant over time. Consequently, we defined as the first sub-period the years 1665 to 1710. Note that in the following discussion, when we speak of a certain variable or "average" of this variable, we **always** mean the average of an explanatory variable calculated for the first 16 years of an individual's life, including the year of birth.

When all averages of the explanatory variables for the first 16 years of life of an individual were included in the regression, the influence of the rye price had a sign that is again not compatible with expectations, but both climatic variables had the expected sign (table 11, model 15). The specification that contained the average price of rye as well as the real wage has some disadvantages with respect to the interpretation of the estimated coefficients: In calculations of a real wage, the price of foodstuffs is an integral part. In other words, the rye price is used among the price of other items to deflate the nominal wage. This also applies to the real wage series (Pfister 2017) we use. Thus, the interpretation of both the coefficient of the rye price as well as of the real wage is complicated due to the *"ceteris paribus"* nature of OLS coefficients: The coefficient of the rye price measures the effect of a one-unit increase in the rye price on stature given that all other variables are held constant, which includes the real wage. An increase in the price of rye would have to be compensated by either an increase in the nominal wage or a reduction in the price of other goods used in calculation of the real wage. Accordingly, we did not consider a model that includes both terms to be sensible. The conclusion that a model that contains price as well as real wage terms is inappropriate was further substantiated by the fact that the adjusted R^2 was not lower in models (17 to 19) than in model (15). As a consequence, we separated the analysis[243] of rye prices (table 11) from the analysis of real wages (table 12).

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[243] Note that the coefficient estimates in model 15 were qualitatively the same if a dummy for year of subsistence crises based on (Albers 2016) is added to the regressions. This dummy is never significant, so we do not include it in regressions for the ensuing other time periods.

Table 11: Determinants of height: Regression results for years 1665 to 1710

Dependent variable: Predicted height in cm (constrained spline regression depicted in figure 8)					
	(15)	(16)	(17)	(18)	(19)
Average rye price during the first 16 years of life	3.0	-17.4***	-5.8**	-4.5	-4.3
Average winter temperature during the first 16 years of life	0.3			0.3	0.3
Average rainfall during the first 16 years of life	-0.06***		-0.07***	-0.06***	-0.06***
Average total population during the first 16 years of life	0.3				-0.01
Average real wage during the first 16 years of life	1.7				
Constant	162.51***	172.9***	178.8***	177.5***	177.8***
N			46		
Adjusted-R^2	0.7	0.4	0.7	0.7	0.7
F	29.4	44.4	70.5	49.3	37.4

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Significances of the coefficients were identical if standard errors were bootstrapped (1000 replications). The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

When the real wage was excluded from the regression, the rye price had the expected sign (table 11, models 16 to 19), but became insignificant once a control for temperatures was added to the regression (table 11, models 17 to 19). The magnitude of the estimated effect changed substantially between models 16 and 17: A one standard deviation (0.03) increase in the average rye price reduced height by 0.5 cm in model 16, but the effect was reduced to 0.1 cm in model 19. Note that the coefficient of rainfall was robust to variations in the specifications and was always significant. The effect of rainfall was of considerable size, as an increase in the amount of rainfall by one standard deviation (8.3) reduced height by 0.5 to 0.6 cm. The effects of rye prices and the climatic variables were robust to the inclusion of the population variable, but the coefficient of this variable was not significant and of an extremely small magnitude (model 19).

Complementary results emerged for the real wage (table 12), but not in every specification: The real wage alone did not explain any of the variation of the estimated heights and the coefficient was insignificant (model 20). The effect was largest in the specification that contained only the average real wage and the average population as explanatory variables (model 24). In this case, as a one standard deviation (0.3) increase in the average real wage lead to an increase in height by 1.3 cm. Similar to the analysis of the influence of the grain price, the rainfall always had a significant effect (models 21 to

23) when controlling for the real wage. Inclusion of temperature rendered the coefficient of the real wage insignificant (model 22), and despite its increase in magnitude when we also controlled for population, it remained insignificant (model 23). The effect of temperature was never significant but of the same magnitude as in table 11.

Table 12: Determinants of height: Regression results for years 1665 to 1710

Dependent variable: Predicted height in cm (the constrained spline regression depicted in figure 8)					
	(20)	(21)	(22)	(23)	(24)
Average real wage during the first 16 years of life	0.3	0.4*	0.3	1.1	4.4***
Average winter temperature during the first 16 years of life			0.3	0.3	
Average rainfall during the first 16 years of life		-0.08***	-0.07***	-0.06***	
Average total population during the first 16 years of life				0.2	0.9***
Constant	165.8***	176.8***	176.0***	168.2***	131.0***
N	46				
Adjusted-R^2	-0.01	0.7	0.7	0.7	0.4
F	0.8	59.4	45.3	38.1	27.9

Sources: see the text. *Notes:* *: $p<0.1$, **: $p<0.05$, ***: $p<0.01$. Significances of the coefficients were identical if standard errors were bootstrapped (1000 replications) except real wage in model 21 which was then significant at 5%. The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

The relationship between population and the nutritional status is theoretically not monotonous[244] which could explain why we did not find a consistent effect of population size (table 11 and 12). So, the signs of the corresponding coefficients in models 23 and 24 could be an indication for what Komlos called a *"Boserupian Episode"* (Komlos 1989, p.218). However, our statement is not on a solid evidential basis and should be further investigated given that better population estimates become available. Baten (2002), citing Komlos, stated that before the middle of the 18th century positive effects of population growth might have been present, but were then replaced by Malthusian effects, as population pressure increased. Note that population had no significant effect in models that include the rye price.

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[244] Komlos argued that *"one should expect a positive correlation to exist between the changes in the rate of population growth and changes in the mean stature in a non-contraceptive, pre-industrial population"* (Komlos 1989, p.34). We could not use growth rates of population in the regressions since our population estimates were linearly interpolated between the years for which population figures were available.

We do not think that the objection, that total population is simultaneous with stature applies to our specification. Our population variable captures the size of the population during the growth stage, and although fertility reacts to the nutritional status (see for example, the model in (Komlos 1989)), this effect manifests itself only after the growth stage, unless an individual started to procreate during adolescence. That is, the nutritional status will probably affect population growth, but with a lag of more than 16 years.

In the second sub-period (1711 to 1762), no specification where total population was excluded yielded convincing results: The estimated effect of the rye price was always positive, and the estimated effect of the real wage was negative. This was true irrespective of whether one or both climatic controls were also added to the regressions (results not shown). Once the average total population was included, the additional inclusion of climatic controls changed the estimated coefficient of the average rye price only slightly (not shown). The estimated coefficient was always negative. The estimated coefficient of the real wage was only significant if at least temperature was also included in the regression (in addition to population), but positive in any case. Thus, we exclusively show the regression results of the "fully specified" models (table 13).

Table 13: Determinants of height: Regression results for years 1711 to 1762

Dependent variable: Predicted height in cm (constrained spline regression depicted in figure 8)		
	(25)	(26)
Average rye price during the first 16 years of life	-24.0***	
Average winter temperature during the first 16 years of life	-1.8***	-2.5***
Average rainfall during the first 16 years of life	-0.07***	-0.08***
Average total population during the first 16 years of life	1.4***	1.8***
Average real wage during the first 16 years of life		5.1***
Constant	154.0***	117.9****
N	52	
Adjusted-R^2	0.6	0.6
F	38.0	27.0

Sources: See the text. *Notes:* *: $p<0.1$, **: $p<0.05$, ***: $p<0.01$. Significances of the coefficients were identical if standard errors were bootstrapped (1000 replications). The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

The estimated effect of rainfall was always significant and larger[245] in absolute terms than the effect estimated for the first sub-period (table 13, models 25 and 26). The effects of

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[245] A one standard deviation (10.6) increase in rainfall reduced height by 0.7 cm to 0.9 cm.

total population and rye prices retained the signs from the previous regressions, but were of a stronger magnitude[246] (table 13). Winter temperature has a different influence compared to the first time period. The effect was quite pronounced but contrary to expectations. One explanation could be the general downward trend in temperature in the second half of the 18th century that exerts and influence on the 16-year averages (figure 24).

Population growth appeared to correlate positively with stature irrespective of whether the averages rye price or the real wage were included as explanatory variables. Does this result warrant skepticism towards the previously proposed conjecture that population pressure lead to a Malthusian threat and a subsequent decline in stature in the second half of the 18th century? We are convinced that sufficient evidence exists to support the conjecture that the threat of a Malthusian crisis was impending. We added an interaction of a dummy for years after 1754 and total population to the regressions. This interaction allows for the effect of population growth to vary with time. The results indicated that even after 1754, the effect of total population on stature was positive, yet smaller than before. This suggests that the positive effects of population growth began to disappear (table 14). That being the case, the estimated effect of rye price was still negative, and of sizeable magnitude, but not significant. Real wage had the expected sign, but was not significant, too. Furthermore, the effect was substantially smaller than previously estimated (table 14).

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[246] This also holds for effects on a one standard deviation change in the respective explanatory variable.

Table 14: Regression results for years 1711 to 1762 including interaction terms

Dependent variable: Predicted height in cm (constrained spline regression depicted in figure 8)		
	(27)	(28)
Average rye price during the first 16 years of life	-8.9	
Average winter temperature during the first 16 years of life	-2.1***	-2.3***
Average rainfall during the first 16 years of life	-0.03**	-0.03*
Average total population during the first 16 years of life	1.3***	1.3***
Average total population during the first 16 years of life * years after 1754	-0.1***	-0.1***
Average real wage during the first 16 years of life		0.9
Constant	146.1***	139.4***
N	52	
Adjusted-R^2	0.7	0.7
F	103.8	69.7

Sources: see the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Significances of the coefficients were identical if standard errors were bootstrapped (1000 replications) except rainfall in model (27) which was then significant at 10%. The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

To sum up, the regression results confirmed to a large extent the pattern found in the previous discussion of one to one correlations between stature and a single possible determinant. The directions of the influences were in most cases identical to the ones found in the non-regression results. Significance of the effects could not always be established, but this was most likely the result of the very small sample size.

When we used the estimated height of youth as the dependent variable, we found some different results compared to the previous results: In the first time period from 1671 to 1710, we also found a consistently negative effect of rye prices on stature, but significant in all specifications identical to those in table 11, models 16 to 19. As far as real wages are concerned, we only found a positive effect of real wages on the stature of youth if we also included a control for population. In all other specifications, we did not find a significant effect of the real wage on the height of youth, and the estimated coefficients were negative and insignificant. Contrary to the results presented in tables 11 and 12, we did not find a significant effect of rainfall on stature in all specifications and the estimated coefficients of winter temperature were negative, albeit never significant. For the second time period, results using height of youth as the dependent variable were qualitatively identical to those reported in table 13. Compared to the results in table 14, however, rainfall was insignificant (with very small and positive coefficient estimates) and the estimated coefficient of real wage was now negative but still insignificant. All results concerning youth can also be found in the appendix.

So far, our approach was based predicted heights as dependent variable, so that in the preceding regressions, each year of birth contributed one observation, that is, it received the same weight. This approach, however, did not reflect the composition of the sample we have used to calculate the secular trends in height. Consequently, we also directly added the explanatory variables to the regressions that were run in chapter 1, where we used observations for the entire Empire[247]. Note that every model reported below *always* contains the following control variables that were also used in the main text: Controls for special troops, Imperial Circles, ages until 23, dummies for decades of birth and a dummy for enlistment during war. For the sake of readability of the tables, the estimated coefficients of these variables are not reported. Since the years of birth were not as evenly distributed as was necessarily the case where we used predicted heights as dependent variables, we did not split the sample by time periods. The regression specification can be summarized as follows:

$$height_i = \boldsymbol{x_i}\boldsymbol{\beta} + \boldsymbol{z_i}\boldsymbol{\gamma} + u_i$$

where:

- $height_i$ is the height of recruit i *and* $i \in \{1, \dots, 64{,}843\}$
- $\boldsymbol{x_i}$ are the same explanatory variables used in tables (11 and 12)
- $\boldsymbol{z_i}$ are all explanatory variables from model 2 in table 3 in chapter 1
- u_i is the error term.

The parameters $\boldsymbol{\beta}$ and $\boldsymbol{\gamma}$ were then estimated by truncated maximum likelihood, constrained and unconstrained.

We found a negative effect of the average rye price on stature (table 15). The effect was sizeable, where a one standard deviation (0.04) increase in the 16-year average rye price reduced height between 0.4 cm and 0.2 cm. However, the estimated coefficient of rye prices was not significant when climatic variables were added to the regressions (models 31 to 34). Rainfall also had a sizeable and significant negative effect. Moreover, we also detected a negative effect of the winter temperature on stature, which is contrary to expectations. All specifications reported in table 15 were qualitatively robust to the

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[247] That is to say, we repeated parts of the analysis from table 3, but we supplemented the regressions with the determinants of height.

inclusion of a control for the average population (not shown). This population control was never significant.

Table 15: Truncated regression including additional control variables.

Dependent variable: Height in cm	Adults and youth					
	(29)	(30)	(31)	(32)	(33)	(34)
Average rye price during the first 16 years of life	-7.3*	-8.9*	-6.2	-7.6	-5.1	-6.2
Average winter temperature during the first 16 years of life			-0.6***	-0.7***	-0.6***	-0.7***
Average rainfall during the first 16 years of life					-0.03**	-0.03**
Sigma	5.8***	constrained	5.8***	constrained	5.8***	constrained

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted to cm for the table. Results were rounded to one, respectively two decimal places. In models (30), (32) and (34), Sigma was constrained to 2.534 Fi (6.86 cm). All models included controls for special troops, Imperial Circles, ages until 23, dummies for decades of birth and a dummy for enlistment during war.

As a complementary regression, we used the average real wage in the first 16 years of life as the primary explanatory variable. The coefficient of real wage had the expected sign, and was significant when no additional climatic control variables were added (models 35 and 36). The effects of rainfall and temperature were identical to the ones in table 15. The results were robust to the inclusion of a population variable[248].

Table 16: Truncated regression including additional control variables.

Dependent variable: Height in cm	Adults and youth					
	(35)	(36)	(37)	(38)	(39)	(40)
Average real wage during the first 16 years of life	1.6*	1.9*	1.3	1.6	1.3	1.6
Average winter temperature during the first 16 years of life	-	-	-0.6***	-0.7***	-0.6***	-0.7***
Average rainfall during the first 16 years of life	-	-	-	-	-0.03**	-0.03**
Sigma	5.8***	constrained	5.8***	constrained	5.8***	constrained

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted to cm for the table. Results were rounded to one, respectively two decimal places. In models (36), (38) and (40), Sigma was constrained to 2.534 Fi (6.86 cm). All models included controls for special troops, Imperial Circles, ages until 23, dummies for decades of birth and a dummy for enlistment during war.

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[248] Note that average population was significant at 10% if temperature and real wages were included in the regression

Our regression result complemented the previously established results. An increase in the price of rye, the primary resource used to manufacture the staple food, exerted a negative influence on stature. An increase in the real wage had the opposite effect. These two results are also internally consistent, since the real wage is in part determined by the level of the rye prices. The effect of the climate on stature was ambiguous: While rainfall had the theoretically expected negative effect, an increase in winter temperature also had a negative effect. We also estimated alternative models where we allowed the effect of the explanatory variables to be different at birth and in the 15 years after birth. Rye prices and real wages had the expected signs in these regressions and were robust to variations in the number of variables included, but the effects of averages after birth were not significant when values of explanatory variables at birth were included in the regressions. These results can be found in the appendix. Because the signs of the estimated coefficients at birth were in line with the results presented here, we concluded that the regressions in the appendix further substantiated the results we presented here.

2.2. Cross-sectional pattern

As was the case with the secular trend, in this section we demonstrate that a single factor is unlikely to explain the cross-sectional variation in stature we document[249]. On the contrary, a combination of certain causes can help to explain the differences in stature between Imperial Circles.

Some channels have been discovered that influence the cross-sectional variability of height within a given[250] population: Urbanization, agricultural productivity[251] and population density are among them.

Our proxy for urbanization in the regional regression was a dummy variable whether a soldier was born in a Free or Imperial City. Hartmann (1995) estimated that approximately[252] 3% of the population of the HRE lived in such a territory. Our regional estimations implied that an urban penalty might have existed in the Empire. Except for the East (table 5), we found a negative effect of being born in a Free or Imperial City but it was only significant for the south (tables 6 and 7). The dummy for Free and Imperial Cities used in the regional regressions may be an imperfect proxy for urbanization, so we chose a second proxy based on the cities and towns in Bairoch et al. (1988). We defined a dummy for "city" which took the value 1 if a population figure was available for this city in Bairoch et al. (1988) for the years 1700 or 1750 (or both). We added this dummy variable to the regressions in chapter 1. When urbanization is measured using this dummy variable, results were ambiguous: When the dummy was included in the

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[249] In the present section, we mainly refer to the variation in stature we find based on models (1) and (2), and the predicted heights by Imperial Circle found in table 4. This is of course a simplification that we discuss in detail below. We cannot discuss reasons for the variability of height within a certain region of Imperial Circle extensively, because the Empire is too much of a heterogeneous entity. We only discuss certain aspects of urbanization, population density and agricultural productivity. A complete study of the differences in stature within a region is reserved for future research. This endeavor may prove to be fruitful, since a vast number of regionally confined studies of the economic and social structure of small regions within what is now Germany could provide detailed information that might be linked to our anthropometric data. As an example of a regional study, consider Robisheaux (1989), who studies the rural society in the County of Hohenlohe in the Franconian Circle during the 17th century. For a bibliographical source on, but is not limited to, European regional studies, see Ogilvie and Cerman (1996).

[250] By given population we describe a group with a homogenous genetic basis. We are not discussing the variation in height between different genetic populations here.

[251] Heyberger (2007) established a link between height and agricultural productivity in different regions of France.

[252] The percentage is 3% or 2.8% depending on whether Silesia was included or not. When Silesia was included, the number was 2.8% (Hartmann 1995).

regressions for the entire HRE, the corresponding coefficient was negative, but of a very small size and insignificant[253].

In the regional regression for the East, we found a substantial positive impact of urbanization, consistent with the sign of coefficient of the dummy for Free and Imperial Cities estimated in the regressions in chapter 1, but the effect had now a much larger magnitude[254] and was significant. In the Central-West region, the coefficient of the urbanization-dummy had the expected negative sign, was of a larger magnitude in absolute terms than the coefficient of Imperial Cities in table 6, and was now significant. In the south, the estimated consequences of urbanization were still negative, but the magnitude of the effect was greatly reduced in comparison to the estimate based on an Imperial City dummy. In addition, the coefficient was not significant. Urbanization was slightly beneficial for stature in the Frontier Zone, but not significantly. No Imperial Cities were located[255] in the Austrian Circle, nor in Bohemia, Moravia or Silesia. Therefore, the regional regression did not contain a measure of urbanization up to this point. Even with the new definition of urbanization, we could only assess the effect of urbanization for the Austrian circle, but not for Bohemia, Moravia and Silesia. The reason was that we did not identify the locality of birth for soldiers who were born in one of those territories in our geocoding process[256]. The outcome of the regression was again counter-intuitive, with a coefficient of urbanization that was positive, significant at 10% and of a substantial magnitude[257]. Nevertheless, since our main focus lies on the secular trends in height, we do not investigate this matter any further.

The regressions that included the Imperial City dummy in addition to the other variables produced for the Empire in total, as well as on the regional level, except for the Habsburg

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[253] For these regressions, Bohemia was excluded since we did not try to identify places of birth in this territory. The coefficient is -0.1 cm in the unconstrained and constrained regressions. None of the coefficients was significant. Komlos (2003) pointed out a potential reason for this phenomenon: *"[...] the recorded town of provenance was perhaps not the actual municipality from which the recruits originated, but might have included its environs."* (Komlos 2003, p.161). Komlos made this statement with respect to soldiers born in France, but it is very likely that corresponding irregularities with respect to the recorded town of birth also exist in our dataset. We thank John Komlos for suggesting this solution to us.

[254] The effect was 0.9cm in the unconstrained regression and 1.2cm in the constrained regression. Both coefficients were significant at 5%.

[255] This statement only refers to Imperial Cities that still existed after the Thirty Years' War.

[256] The reason is that the soldiers may have provided the names of the localities in German, but today the localities bear Polish or Czech names. We were unable to obtain a source that depicts the geographic location of 18th century towns in Bohemia, Moravia or Silesia in German. The costs associated with geocoding these observations considerably outweighed the gains, so we decided against it. This leaves room for future research of an urban penalty in Bohemia, Moravia and Silesia.

[257] 1cm in unconstrained and 1.3cm in constrained regressions.

possessions[258], secular trends that were qualitatively identical to the trends without the city dummy. So, the secular trends we estimated were not subject to an omitted variable bias caused by not controlling for urbanization. The fact that we did not find signs of an "urban penalty" is related to Komlos' (2003) results for France: He did not find an effect of the logarithm of population size in his regressions, except for Paris.

Estimates of regional population growth were not available[259] for the time span we study. Hartmann (1995) calculated the population of the Empire by Imperial Circle in 1795, which gives us an approximation of the distribution of the population between Imperial Circles at the end of the 18th century. We combined his estimations with our own calculations[260] of the surface area of the Imperial Circles to produce an approximate measure of population density for each circle in 1795. This approach had its obvious limitations, but it was our only option given the available data: As our height estimates, we used the estimated heights for each Imperial Circle based on the constrained regression for the entire Empire (model 2). Thus, the dummy variables for Imperial circles capture the average differences in stature for the whole period covered by our data.

The results indeed imply a negative relationship between population density and the nutritional status (figure 26). With respect to the Alsace, our results were in agreement with Heyberger (2007), who noted that the rural Alsace had a high population density.

However, some combinations of height and population density did not seem to fit the pattern: Burgundians and soldiers from Upper Rhine were exceptionally tall given the high population density in these circles, and contrast to recruits from Austria and Bavaria who were exceptionally short given the relatively low population density there.

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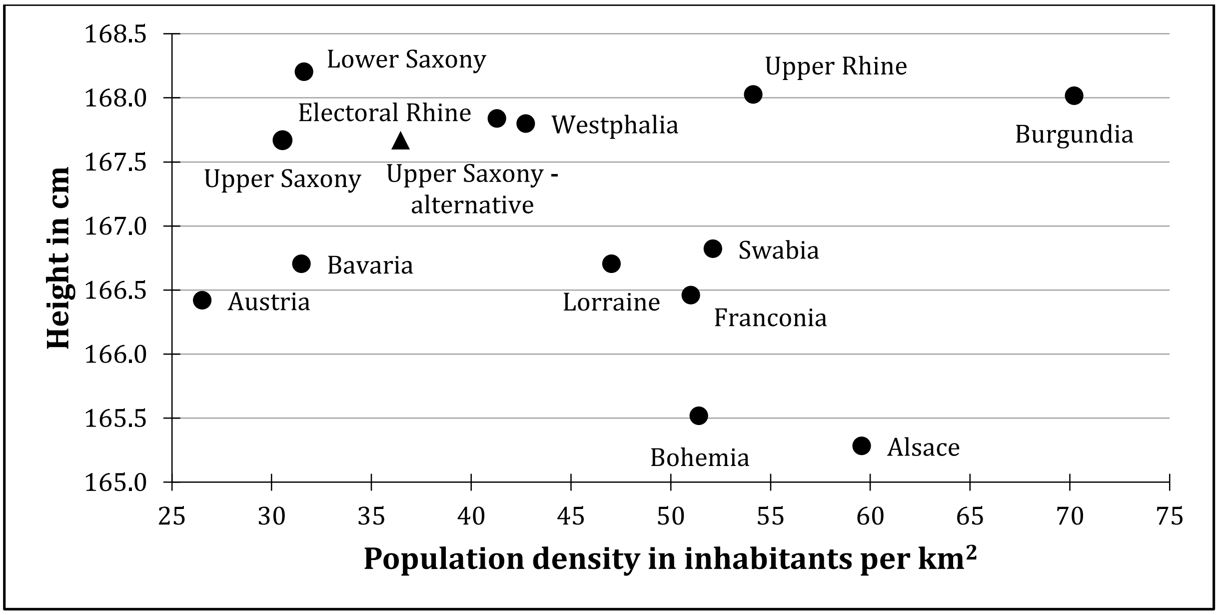
[258] Since we excluded Bohemia, Moravia and Silesia, the composition of the sample was altered, and so are the predicted trends. Yet, the pattern of the new trends was still highly comparable to the trends for the Habsburg possessions we previously estimated.

[259] Pfister and Fertig compared existing regional studies of population growth, but the series they reported began in the 1750s (see Pfister and Fertig, 2010, p.10, table 3).

[260] See appendix for details.

Figure 26: Estimated height and population density by Imperial Circle in 1795



Sources: Heights from table 4, predictions based on chapter1, table 3, model 2. *Notes:* Population density was calculated using population figures in Hartmann (1995) and Dupâquier (1988), divided by the surface area of each Imperial Circle. Surface areas of the Imperial Circles were our own calculation using an existing GIS software. The triangle "Upper Saxony - alternative" used the actual surface area of the Upper Saxon circle in the calculation the population density while the dot "Upper Saxony" was based on the extended definition of the Imperial Circle. See appendix for details.

Can the results with respect to the outliers Austria, Bavaria, Upper Rhine and Burgundy be explained or reconciled with the general findings? We demonstrate that the answer to this question is yes[261]. In particular, when we augmented the previous figure with regional estimates of stature around 1795 calculated by other researchers, we could clarify the sources of the deviations we found (figure 27).

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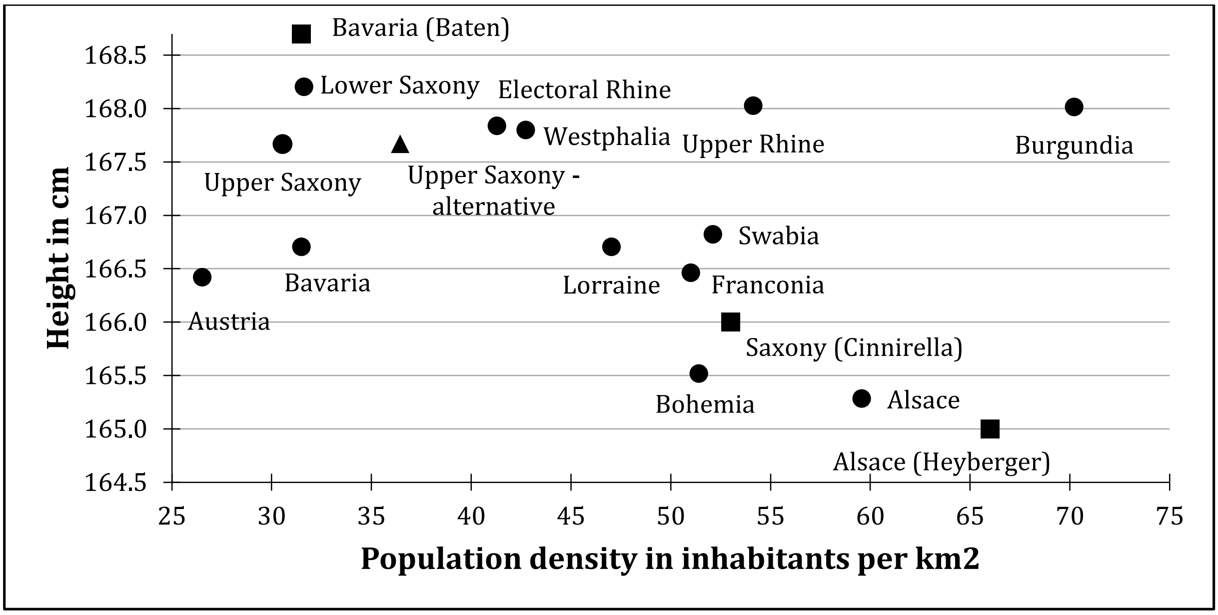
[261] We used evidence from existing literature to illustrate our reasoning. Of course the reader should bear in mind that the territorial definitions change somewhat between our study and the literature we refer to.

Figure 27: Estimated height and population density by Imperial Circle in 1795, with region specific estimates of stature



Sources: Dots: Heights from table 4, predictions based on chapter1, table 3 model 2. *Notes:* Population density was calculated using population figures in Hartmann (1995) and Dupâquier (1988), divided by the surface area of each Imperial Circle. Surface areas of the Imperial Circles are our own calculation using an existing GIS software. Squares: Bavaria (Baten 2002), Saxony (Cinnirella 2008), Alsace (Heyberger 2007). For detailed references to the sources, see the text. The triangle "Upper Saxony - alternative" used the actual surface area of the Upper Saxon circle in the calculation the population density while the dot "Upper Saxony" was based on the extended definition of the Imperial Circle. See appendix for details.

There were several reasons why we found these outliers in our data: Firstly, it should be noted that the relationship we document here was not stable over time. Bavaria is the prime example for a trajectory of stature after the 1760s that puts Bavaria in 1795 in a different sector of the figure than before: Bavarians born in the cohort of 1790 to 1795 were approximately 168.7 cm tall[262] (Baten 2002). Baten did not provide numbers for the population density in Bavaria, so we used our estimated population density. How could Bavarians experience such an improvement in the nutritional status after the second half of the 18th century? The rate of population growth[263] in Bavaria was lower compared to the average in Germany, and in particular it was lower than in Lower Austria, and much lower than in Bohemia or Palatinate. The position" of Bavaria in figures 26 and 27 is consequently the result of uneven growth-paths between 1763 and 1795. Cinnirella (2008) documented that the nutritional status of Bavarians and Saxons developed in different directions in the last thirty years of the 18th century: Comparing Baten's (2002)

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[262] Value calculated from: (Baten 2002, p. 20, table 5 and p. 21, figure 4. "RSMLE, all army categories" we read off the value in figure 4 so it should be considered an approximation.)
[263] All elements in the following discussion were taken from: Baten (2002, p.10, table 1).

results about Bavaria with his own discoveries, he found a divergence in trends: Bavarians grew taller after 1770 whereas heights in Saxony declined substantially after 1770 (Cinnirella 2008). The previous discussion implied that our calculations were not entirely satisfactory when using the average stature in Bavaria over the entire period of study as a proxy of the nutritional status in 1795. Is Bavaria an exception or does this result imply that we cannot draw any conclusions about the nutritional status and population density given the available data? Bavaria may indeed be an exception. Mountainous landscapes like Bavaria were subject to larger temperature fluctuations (Glaser and Riemann 2009). Since Bavaria as well as Austria are mountainous, climatic fluctuations may have had a greater impact on harvest in comparison to other regions, resulting in a reduced nutritional status. The "catch-up" that Bavarians experienced after the 1770s is to some extent attributable to the introduction of the potato after the subsistence crisis in 1771/1772, accompanied by a recovery of real wages (Baten 2002). Bavarians were dependent on a self-sufficient agriculture with varying access to growth-promoting protein. Baten stated that southern Bavaria depended on dairy products, which are susceptible to climatic fluctuations. We could not assess the influence of protein availability on the nutritional status in the south, since Baten (2002) argued that production series pertaining to meat and milk were not available for southern Germany. Baten (2002) generalized his findings for Bavaria to Austria-Hungary, and he argued that they were as susceptible to climatic fluctuations as were Bavarians.

On the other hand, Cinnirella's (2008) results fit perfectly into the proposed negative relationship: He estimated Saxons in 1795 to be around 166 cm tall[264], at a population density of around 53 inhabitants[265] per km^2. He stressed that the Kingdom of Saxony was already densely populated in early modern times. Furthermore, note that the population density in the Kingdom of Saxony increased after the 1760s, while in the preceding decades it had oscillated around levels of 45 to 47 inhabitants per km^2. This population density is higher than what we calculated for Upper Saxony as a whole[266], but fit very well to our regression results in chapter 1: Inhabitants of the Kingdom/Electorate of Saxony

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[264] We read off the values from: (Cinnirella 2008, p.245, figure 4), so they should be considered approximations.

[265] We read off the values from: (Cinnirella 2008, p.232, figure 1), so they should be considered approximations.

[266] The fact that we calculated a lower population density can be attributed to the fact that the Upper Saxon Circle encompassed more territories than just the Kingdom respectively the Electorate of Saxony.

were significantly shorter than recruits born in the less densely populated Hohenzollern possessions (table 5).

Heyberger estimated Alsatians to be 165 cm tall[267] in 1795. The population density in Alsace was 66 inhabitants[268] per km^2 in 1806 (Bardet and Dupâquier 1998). This again reaffirms the pattern we documented. The dynamics in Alsace are sensitive: Population density further increased and stature further declined.

Burgundia constitutes a special case. Our models predicted recruits from this Imperial Circle to be very tall despite living in a territory with a high population density. In fact, the number of inhabitants per km^2 is highest among all Imperial Circles, and Burgundians were still among the tallest people in the Empire. Based on Bairoch et al.'s (1988) data, we calculated the rates of population growth[269] for the cities in Burgundy. Between 1700 and 1750, this rate was actually slightly negative[270] but turned positive for the era 1750 to 1800. Rather, the contrary was the case for Bavaria and Austria: Cities continuously grew at an accelerating rate from 1700 to 1800 (figure 28) These cities with their growing demand for food could have depleted the countryside of its nutrients[271]. On the other hand, a similar phenomenon could explain the high nutritional status in Upper Rhine: City growth decelerated substantially in the second half of the 18th century.

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[267] We read off the values from: (Heyberger 2007, p.239, figure 4. "Provincial estimates"), so they should be considered approximations. Note that Heyberger (2007) also calculated the height of inhabitants of the "Bas-Rhin" (northern part of Alsace). In the cohort of 1790-1794, they measure 163.5 cm

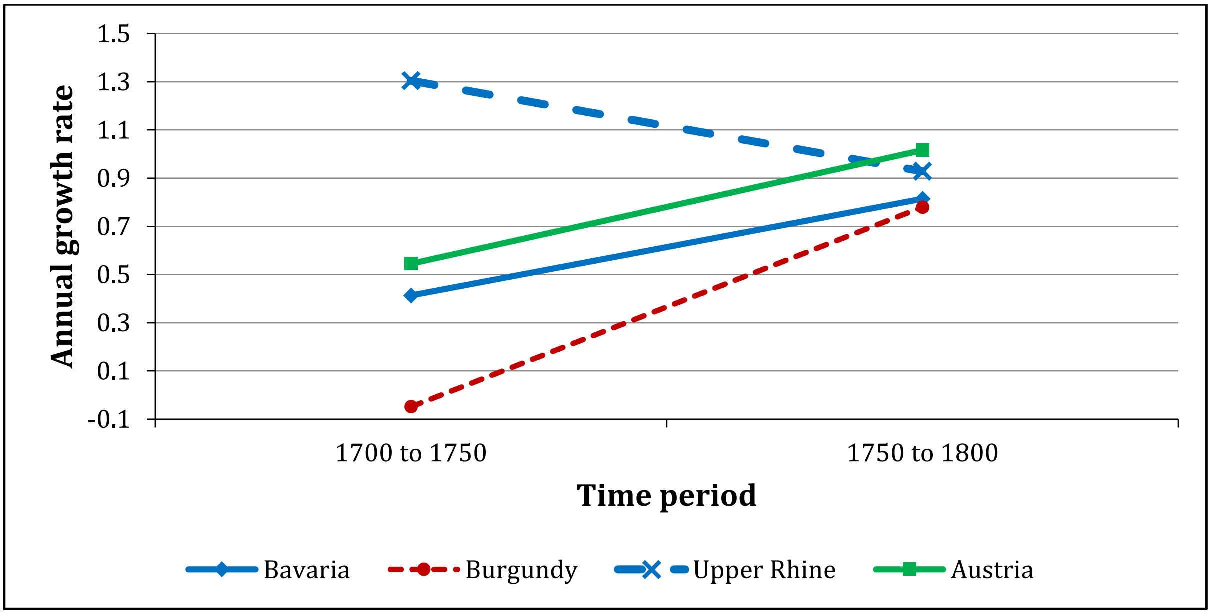
[268] Value from: (Bardet and Dupâquier 1998, p.293, figure 43).

[269] We considered this explanation insufficient to explain the entire height advantage of Burgundians, and we present a second possible explanation below.

[270] The growth rate is -0.05% per year based on the assumption of a geometric average growth rate and a time span of 50 years.

[271] We thank John Komlos for suggesting this explanation.

Figure 28: Average yearly growth rate of cities in four Imperial Circles



Sources: See the text. Data on population from Bairoch et al. (1988) was used to calculate geometric average growth rates.

Austrians were comparatively short given the low population density in the Austrian Circle. Komlos (1989) ascribed the height differentials he found between regions of the Habsburg Empire at least in part to the protein output per capita. He found that caloric and protein output was lower in Bohemia and Lower Austria compared to other parts of the Habsburg domain. This may contribute to the low nutritional status of Austrians and Bohemians. Ogilvie (1996) partitioned the southern part of the HRE into three large[272] territories: Bavaria, Württemberg and Austria. Farming as well as the proto-industry were strictly regulated[273] in the south (Ogilvie 1996). An inflexible agricultural structure could have contributed to a low nutritional status. Economic policies were hard to implement in Austria, since landlords were powerful and were endowed with a huge degree of autonomy (Cerman 1996). This might be interpreted as a sign of inflexibility of the agrarian sector, contributing to a low caloric output per capita.

A closer examination of the within-circle connection of stature and population density revealed that the negative relationship between heights and population density held *within* the Burgundian Circle: Population density estimates for the end of the Middle Ages

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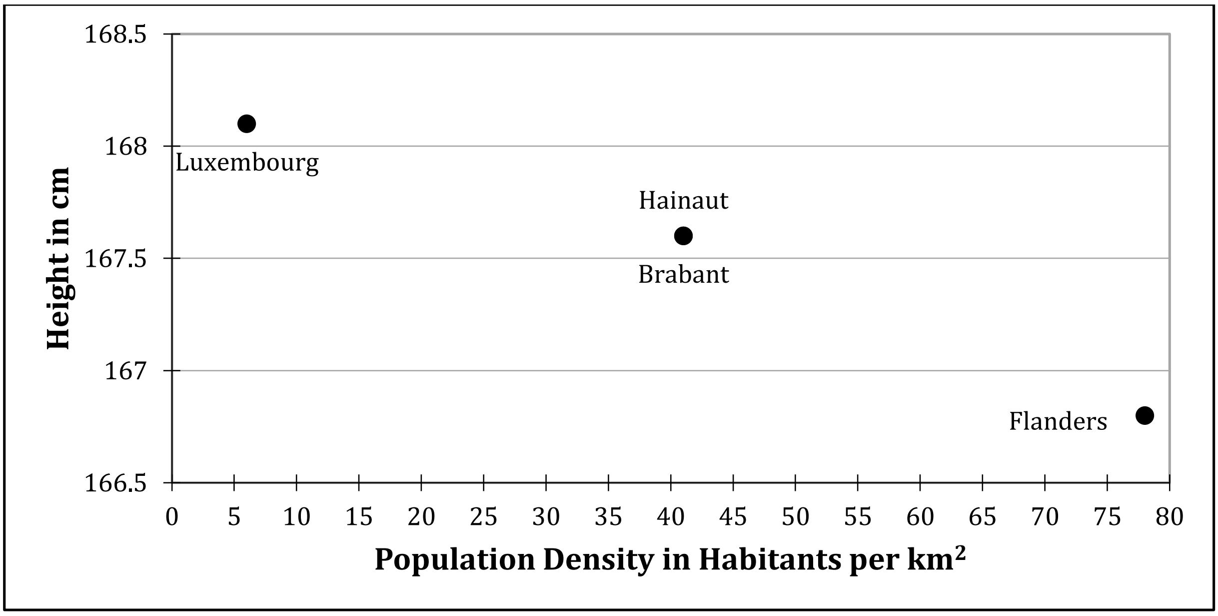
[272] Many more territories existed in the south, but the degree of fragmentation was very high, therefore the other territories were small.

[273] Ogilvie (1996) attributed the high degree of regulation to a shift in the economic circumstances: After the Thirty Years' War, the economic center of the Mediterranean lost its leading role, when economic activity shifted more towards the Atlantic seaboard.

are available in (Bardet and Dupâquier 1997). Flanders was densely populated, with 78 inhabitants per km^2, followed by Hainaut and Brabant with 39 to 41 inhabitants per km^2 and Luxembourg with an extremely low population density of only 6 inhabitants per km^2. To investigate the variation in stature within Burgundia, we re-estimated[274] heights using only observations from this circle. The estimated controls for regions within Burgundia were not significantly different from zero[275], but the relationship[276] between predicted heights and regions within this circle for which population densities were available is shown in figure 29 and confirms the suggested pattern:

Figure 29: Predicted height and population density by sub-regions of Burgundia



Sources: See the text. Population densities: Bardet and Dupâquier (1997). Heights: Own estimation.

A second phenomenon contributed to our prediction of tall soldiers from Burgundy: The distribution of recruits in our sample is skewed towards the "taller" regions Luxembourg (N=1,030) and Brabant (N=1,063) and the equally[277] tall recruits from Hainaut (N=676). Flemish recruits constitute only N=620 observations. Nonetheless, all recruits from

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[274] We estimated a constrained truncated regression similar to model 8: Territorial controls were dummy variables for: Luxemburg, Tournai, Hainaut, Flanders, Namur and one dummy for all territories with few observations. Reference category: Brabant. All other controls and specifications were identical to model 8. Observations that could not be assigned to a territory within Burgundia were discarded. Number of observations in the regression: 5,080. An unconstrained regression yielded qualitatively the same results.

[275] Except for the coefficient of Tournai which is significant at 10% in both regressions.

[276] The figure contains predicted heights based on the regression described in footnote 274. Age controls were set to zero, all other variables including birth-cohort dummies were set to their sample mean. A prediction based on an unconstrained regression only shifts the level of all predicted heights but does not change the overall pattern.

[277] The coefficient of the dummy for Hainaut was estimated as so small and insignificant that difference in predicted heights between these regions amounts to zero, so that both points coincide in figure 29.

Burgundia were still among the taller people with respect to the other Imperial Circles. For example, Flemish recruits were approximately as tall as Swabians, despite living in region with a population density that was approximately 50% higher. One possible explanation can be the advanced agrarian structure of Flanders respectively Belgium. De Vries (1976) stated that the agriculture in Flanders was already advanced in the 17th century. Allen found that agricultural productivity in Belgium was constantly high after 1500, and he called Belgium[278] an *"advanced economy"* (Allen, 2000, p.23) in 1750. Another explanation may be the "ruralisation" of Flanders during the 18th century (Vandenbroeke 1996). This would at least reduce the exposure to diseases that an individual is confronted with in an urban environment.

To summarize, our results for Burgundia do not contradict the finding that population density and stature are negatively related, but instead highlights the importance of further investigations of the within-circle heterogeneity of heights, a task reserved for future studies.

Explanations for the high nutritional status of individuals from the "Rhenish[279]" regions were not as easily found, in particular for the outlier "Upper Rhine". One reason could have been the regional variation[280] in the organization of agriculture (Ogilvie 1996) throughout the Empire. For example, Ogilvie stated that the power of the landlords had already declined before the 18th century, and *"entrepreneurial peasants practiced commercial agriculture"* (Ogilvie, 1996, p.125). We interpreted this as an indication that agriculture was efficiently organized and more flexible compared to, for example, the South. De Vries (1976) drew a similar conclusion. He argued that the "Rhineland" region was integrated into trade, in particular oxen from Denmark in the 17th century. He furthermore explained that the agriculture surrounding the trade hubs in the region was specialized and already oriented toward the market[281]. The results by Baten (2002) contained another possible reason for the high nutritional status of soldiers born in the

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[278] The statement by Allen (2000) mentioned Belgium and the Netherlands.

[279] Note that there exists a semantic ambiguity of the term "Rhineland" in the available sources. Most literature we consulted described the economic situation in what they called "Rhineland", for example (De Vries 1976) and (Ogilvie 1996). More importantly, "Rhineland" can also refer to parts of Westphalia, Electoral Rhine or Upper Rhine.

[280] Kiesewetter (2004) described centers of traditional industry (*"Gewerbe",* p.33) that were regionally confined, but located in all Imperial Circles, so the presence of traditional industry cannot explain why recruits from the Upper Rhine were as tall as their neighbors, despite the higher population density.

[281] But note that market integration need not be beneficial for the nutritional status. See, for example: (Komlos 1998).

(southern) Rhineland: He described the Palatinate, which in part overlaps with the Upper Rhine and the Electoral Rhine, as densely populated, but he also found a higher nutritional status of those born in the Palatinate compared to Bavarians[282]. We calculated a lower population density for the Electoral Rhine compared to the Upper Rhine, but recruits born in the latter were taller. Baten's findings cannot explain tall Upper Rhenish recruits, but they do contribute to the explanation why inhabitants of these two circles are taller than Bavarians, who inhabited a less densely populated circle: Variations in climatic conditions have a stronger effect on the nutritional status in colder regions, and relative to the Palatinate, Bavaria was colder (Baten 2002). After the 1750s, in a climatically more challenging phase, recruits from the Palatinate were indeed taller than their Bavarian counterparts in Baten's (2002) study. The opposite was the case before the 1750s. Therefore, we cannot rule out that favorable climatic conditions can, to some extent, explain why the high nutritional status could be maintained in the Rhineland despite the higher[283] population density than in the south. These accounts, even if they do not refer to the Upper Rhine, but to other "Rhenish" regions, illustrate why the average nutritional status was high in this part of the Empire. What remains to be solved is the puzzle why the Upper Rhine has an exceptional role within the Rhenish Circles.

2.3. Determinants of stature not considered in our analysis

In the existing literature, some factors known to influence height have been ruled out for the era covered in our paper. In addition, we cannot measure the influence of certain determinants due to inadequate data, though, we include a short discussion for reasons of completeness.

2.3.1. Inadequate data

Koch (2012) could not rule out that a variation in the disease environment led to a change in stature in the HRE of the 18th century. Specifically, he referred to possible vaccinations against smallpox[284] that were initiated in the first half of the 18th century. But he added

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[282] Baten only studied these two regions, not the entire Empire.

[283] This argument is further strengthened by the trajectories of our regional trends. Here, the southern regions, of which Baten's (2002) Bavaria is a part of, were indeed shorter than Central-Westerners, of which Baten's (2002) Palatinate is a part of, who were among the tallest in the 1750s. Heights in the regions were almost identical in 1700. The good nutritional status we measured for the Rhineland may very well be in part be explained by the favorable climate in the Rhineland region.

[284] In a debate that stretched over the course of 10 years, researchers debated over the influence of smallpox on heights. The disagreement centered on whether smallpox exposure reduced the height of survivors in comparison to people who were not exposed to the disease. If this were true, a reduction in the incidence

the qualification that the sign and magnitude of the assumed effect are unknown. Since we have studied an epoch that dates back further than the epoch studied in Koch's (2012) work, and taking into consideration that the quality of data cannot be expected to improve with age, we arrive at the same conclusion[285] as Koch (2012). Komlos (1989), provided an argument based on the trajectory of the secular trends in stature that made variations in the disease environment an implausible determinant in the setting of this study. He argued that the reversal in secular trends he estimated[286] towards the end of the 18th century, when the trend of previously increasing heights was reversed and a period of declining stature commenced, is not reconcilable with a change in the disease environment: The reversal in trend from upward to downward would imply a short-lived improvement in the disease environment, followed by a worsening. This is implausible (Komlos 1989). We found a synchronicity of our trends across all regions, so it is unlikely that the trends can be explained by a change in the disease environment, as this would imply a synchronous improvement and a subsequent deterioration of the disease environment in a short period of time and across the entire Empire.

The occupation of the recruits, respectively their father's occupation is not often recorded in our data, and the variation within the occupational categories is too low given that an occupation had been recorded (table 2), to include occupational controls in any of the regressions. We therefore could not assess the effect of the social status on stature. For France, Komlos (2003) found a differential in stature between socio-economic groups as conventional wisdom suggests: A height premium existed for upper-class recruits and recruits who had easier access to food[287] during their growth-phase. Koch (2012) estimated significant effects[288] for the occupational categories "Professional" and "Service[289]". Komlos (1990a) found a height gradient between social classes for students enrolled in a school in southern Germany in the second half of the 18th century.

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of smallpox could mean an improvement in stature (Voth and Leunig 1996). Other researchers disagreed with this finding.

[285] Furthermore, Pfister and Fertig (2010) pointed out the difficulty in gauging the effect of epidemic disease on mortality on a national scale.

[286] He studied trends in stature for East-Central Europe.

[287] The access to food was possible through their fathers' occupations.

[288] Unfortunately, Koch's (2012) regressions did not contain the occupational category "Production" that is most prevalent in our sample.

[289] In our sample, both categories are barely represented (table 2), so we are confident that our results were not distorted by not including controls for the occupational categories.

Mortality data that covers the entire epoch studied in this paper is unavailable. Pfister and Fertig (2010) calculated birth and death rates for Germany dating back to 1690, but they advised against using the data for years before 1730. They argued that the rates they calculated for early years show large discrepancies and the number of observations used in the calculations was low before 1735. The birth rate did not fluctuate substantially for one hundred years after 1740, and death rates started to decline after 1820 (Pfister and Fertig 2010). Imhof (1994) discussed the development of mortality for the German city of Berlin, but only after 1720. He identified major peaks in 18th century mortality in 1740, 1758/1763 and 1772. He explained: *"Es fällt nirgends schwer, den jeweiligen Mortalitätsanstieg auf eine der drei klassischen Ursachen oder deren zusammenwirken zurückzuführen: Krieg, Hunger, Seuchen"* (Imhof 1994, p.33). In particular, he stressed a close connection between the peaks in mortality of the 1740s and 1770s and *"[...] Mißernten von europäischem Ausmaß [...]"* (Imhof 1994, p.33). However, Imhof (1994) argued that the high rate in mortality lasted until 1810, with peaks associated with the previously mentioned causes, whereas a decline[290] in mortality can only be detected after the 1870s. Because of this insufficient variation in mortality in the epoch we studied, we do not discuss this issue any further.

Data on life expectancy was also not available at a sufficiently detailed level. Floud et al (2011) compiled a list of available data on European life expectancy, but only as decadal averages, for both sexes. The series began for today's Germany in the 1740s, but for other parts of the Empire such as today's Belgium, the Czech Republic and Austria, 18th century data is unavailable. There is no uniform trajectory of life expectancy in the second half of the 18th century[291]: Life expectancy at birth declined from the 1740s to the 1760s, increased in the 1770s and remained constant until the 1790s when the life expectancy declined again. The first decline in life expectancy is consistent with the decline in stature we estimated for the second half of the 18th century. Imhof (1994b) provided[292] life expectancies at birth by decade beginning in 1740[293] for male Germans. The 18th century

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[290] Note that Imhof (1994) mentioned that the volatility in mortality decreased from 1810 to 1870.

[291] The subsequent description is based on: (Floud et al. 2011, p. 243, table 5.1). We only discussed decades until 1800.

[292] The description is based on: Imhof (1994b, p.427, table 1.5.2.1.2).

[293] Imhof (1994b) also listed male life expectancies at birth for decades from 1690 on, but only for one City in Southern Germany (Herrenberg). Life expectancy increased from the 1690s to the 1720s, remained relatively constant into the 1740s, declined in the 1750s and 60s, increased again in the 1770s but declined again to a new low in the 1780s. An increase followed in the 1790s, then life expectancy remained constant until 1800. The description is based on (Imhof 1994b, p.455, table 2.5.1.2.).

pattern is the same as the one discussed by Floud et al (2011). Due to the fact that more detailed data is unavailable, we cannot discuss the relationship between stature and life expectancy in greater depth.

2.3.2. Determinants of height unlikely to drive our results

An alteration of the amount of physical exertion may affect the nutritional status through the energy demand (Voth 1995,1996). No real consensus emerged from the literature as to whether this effect is relevant. One prime example of this discussion is the debate between Voth (1995, 1996) and Komlos and Ritschl (1995) over the issue whether the abolishment of some Catholic holidays in Austro-Hungary had an effect on the nutritional status. Baten (2002) is skeptical of this view, and stated that it could not be ruled out that individuals reacted to reduction of holidays by reducing their work effort, which offsets the additional energy demanded by the increase in the number of work-days, resulting in an unchanged nutritional status. Essentially, we interpret Baten's (2002) argument as follows: The amount of physical exertion is constrained by the amount of calories consumed, since there was no "excess" energy available through nutrition[294]. Koch (2012) concluded that the variation in the amount of physical exertion is not known for the 18th century Empire.

Even if physical exertion or a change in the number of holidays occurred, we rule these out an explanation for our results: The synchronicity of the trends we estimated across regions would demand a coordinated change across the entire HRE, which is already ruled out by the excessively high number of sovereign states within the Empire that would have had to coordinate such a move.

Market integration is known to have a possible negative effect on stature: Komlos (1989, 1998). However, Komlos (1989) studied market integration in the Habsburg Empire only after 1760[295]. A customs union between Moravia, Bohemia and Austria was established in 1775 (Komlos 1989), well after the years of birth we analyzed. For the 18th century Habsburg Monarchy, Komlos stated: *"[…] in the middle of the 18th century, large segments of the Habsburg population were isolated from the market […]"* Komlos (1989, p.105). For the HRE, Kiesewetter (2004) provided a striking example that markets were not

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[294] Basically, the amount of work was already a corner solution before the abolition of the holidays, so an increase in the number of work-days could not lead to more physical exertion if the amount of energy consumed was kept constant.

[295] He found negative consequences of market integration for Hungarians.

integrated in the 18th century: He mentioned that even with a *single city* in the Empire, different legal systems might have co-existed. Kiesewetter (2004) concluded that this fact, combined with the existence of a number of tariffs, were obstacles for trade. Consequently, we rule out market integration as one driving force behind our results. On a European scale, Chilosi et. al (2013) conclude that a common market for grain formed in the 19th century. For the 18th century, they could only establish the existence of a widespread regional integration of markets, though a common "German" grain market did not exist.

Livi-Bacci (1991) mentioned that the eating habits of Europeans were influenced by the introduction of new crops such as potato[296] from the 17th century on. He argued that the new crops diversified the harvests and increased the yield per unit of land, so we would expect a positive influence of the potato on the nutritional status. He drew the conclusion that *"By the latter part of the eighteenth century the potato had conquered Europe"* (Livi-Bacci 1991, p.95). However, some qualifications to this statement render it unlikely that a variation in the nutritional habits are the driving force behind our results: Firstly, the spread of the potato does not coincide with the era we studied: De Vries (1976) stated that the potato was introduced in most of northern Europe after 1740. The potato became widespread after the famines in Central Europe of 1770 to 1772 (Livi-Bacci 1991). Sandberg and Steckel (1980) stated that the potato became a field crop in Sweden in the first half of the 19th century. Ogilvie and Cerman (1996) mentioned that in some parts of the Empire, the potato was introduced earlier. As far as the relative importance of the potato is concerned, De Vries (1976) pointed out that the potato, introduced in Flanders in the first decade of the 18th century, covered only 15% of the arable land in East Flanders in 1800. While the potato was unevenly spread across the Empire, and later than the period we studied, the synchronicity of the trends we estimated lead us to the conclusion that the introduction of new crops was not a primary force that drives our results.

Furthermore, the effects of new crops on the nutritional status are ambiguous: Livi-Bacci stated that the introduction of new crops did not necessarily increase the available harvest per head, as population also increased: *"[...] the demographic expansion of the eighteenth century became a running battle between population and resources [...]"* (Livi-Bacci 1991, p.96). On the contrary, he came to the conclusion that the positive effects of

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[296] The potato was important in Central and Northern Europe, while maize was important in Southern Europe (Livi-Bacci 1991).

the introduction of the potato were to a large extent compensated for by population growth. In addition, the caloric content per unit was also not identical between the new crops and the old ones, with the consequence that *"in more than one case the substitution of a diet with a lower caloric content per unit weight led to a deterioration of the overall nutritional level"* (Livi-Bacci 1991, p.96). Additionally, there was a general decline in meat consumption in the 17th and 18th century (Livi-Bacci 1991). This cannot explain the short-term variation in stature we documented, though it fits the overall picture that the nutritional status did not improve in the period of time studied here. Livi-Bacci's conclusion is consistent with our inference: *"[...], more than one reasonable doubt exists as to the extent, or even existence, of dietary improvements before the nineteenth century"* (Livi-Bacci 1991, p.99).

2.4. Conclusion

In conclusion, our findings confirm the patterns found in the existing literature about stature in the early modern HRE, on the regional as well as on a nation-wide level. We extend the knowledge about the nutritional status back into the second half of the17th century. The Empire was no exception in the continental European context: The population was susceptible to fluctuations in the agricultural conditions, and the frequent subsistence crisis of the 17th and early 18th century took their toll. With the increase in population growth in the second half of the 18th century, a growing population had to be nourished by an agriculture whose productivity could not keep pace with the rising demand for food. This manifested itself in a decline of the nutritional status throughout the HRE. This finding adds further evidence to the argument made by Komlos (1989, 1998) that the nutritional status declined in the second half of the 18th century as a result of a Malthusian crisis. Despite secular trends that move in common directions in all regions of the Empire, the magnitude of upswings and downswings in height is different between the north and the south, leading to the emergence of a north-south gradient in stature after the second half of the 18th century. We demonstrate agricultural conditions and climatic variations are the most plausible causes of the trends we estimated.

The cross sectional variation in stature we document in this study highlights the importance of the agricultural structure and to some extent population density to explain cross-sectional differences in stature. A more advanced agricultural structure was able to maintain a relatively higher nutritional status of a population even when population density was very high. Given this, even a more progressive agricultural system could maintain a high nutritional status only to a certain extent. Continued or accelerating population growth unambiguously led to the threat of a Malthusian crisis and decline in the nutritional status.

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3. Height and grain prices in the 17th and 18th century: Evidence from French army records

In the anthropometric literature about heights in the 18th century, a common line of reasoning can be detected: The overwhelming majority of existing research points to a decline in the nutritional status in the second half of the 18th century[1]. Such declines have been identified for England[2] (Komlos 1993a, 1993b, 1993c, Cinnirella 2008a, Komlos and Küchenhoff 2012), the Holy Roman Empire (Komlos 1985, 1989, Baten 1999, 2002, Cinnirella 2008b, Koch 2012, and our results in the previous chapters), France (Komlos 2003), Italy (A'Hearn 2003), Russia (Mironov and A'Hearn 2008), Sweden (Sandberg and Steckel 1987, Heintel et al. 1998), Finland (Penttinen et al. 2013), Scotland and Ireland (Koch 2012) and Portugal (Stolz et al. 2013).The actual decades in which the decline commenced vary depending on the span of birth decades studied in the respective papers[3].

There is consensus in the literature about the possible causes of the deterioration of the nutritional status: Most studies[4] argue that a rise in food prices combined with an increase in population growth were primary drivers of the decline in stature. The threat of a Malthusian crisis was looming, but did not materialize in the end because of structural changes and progress in agriculture (Komlos 1993a). Other contributing factors that were mentioned are famines (Sandberg and Steckel 1987, A'Hearn 2003), changes in consumption patterns (Komlos 1993c, 1998, Nicholas and Steckel 1997), as well as the climate (Baten 2002, Komlos 2003). One exception is the paper by Mironov and A'Hearn (2008). They specifically exclude population pressure as a driving force behind their

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[1] The following summary is confined to 18th century results, and excludes any results in the discussed literature about 19th century heights.

[2] See for example: Some controversy surrounds the nutritional status of the English, in particular the trajectory of heights in the 18th century: Floud et al. (1990, 1993) took an optimistic stance and found that heights increased somewhat in the second half of the 18th century. Their approach in handling the data has been criticized by Komlos (1993a, 1993b, 1993c), who estimated a decline in stature instead. Using convict data, Nicholas and Steckel (1992) found a decrease in stature after 1780, and Cinnirella (2008a) confirmed a decline in stature after the 1750s, using parts of the dataset from Floud et al. (1990). Again using the "Floud-dataset", Komlos and Küchenhoff (2012) estimated a long-term decline in stature starting in the 1740s. For a more detailed overview of the discussion, see Floud et al. (2011, pp.134-139).

[3] See Komlos and Küchenhoff (2012, figure 6, p.55) for a list of the rates of decline in height of European populations.

[4] (Koch 2012, Komlos 1993a, 1993c), (Baten 2002), (A'Hearn 2003) (Komlos and Cinnirella 2008), (Cinnirella 2008a), (Komlos and Küchenhoff 2012).

results. Rather, they attributed their findings in respect to the 18th century to exploitation and taxation.

Using new data, we study primarily the late 17th and the first half of the 18th century, extending the existing knowledge about the nutritional status of several European populations. We thus provide a building block that can complement the existing literature and provide evidence on the development of heights before the nutritional status began to decline in the second half of the century. Because our data covers also the 1760s, we can furthermore assess whether this decline can also be detected in our dataset. We also add evidence of the nutritional status in the 17th and 18th century for previously un-researched European countries. Finally, we assess the influence of grain prices on the nutritional status of pre-industrial Europeans, an approach that, complements Baten's (2000) study of height and real wages in the 18th century.

We found that trends in the development of heights were not uniform across countries, and we present evidence that the nutritional status of pre-industrial European populations was influenced by fluctuations in grain prices, whereas the intensity varied between the different countries.

This chapter is organized as follows. In section 2 we analyse the data structure and describe the econometric methodology used. Section 3 contains estimates of mean height for those countries where the number of observations did not permit the estimation of trends. Secular trends in stature in six European countries are estimated in section 4. In section 5 we analyze whether grain prices contribute to the explanation of the trends. Section 6 is the conclusion.

3.1. Data and Methodology

Our dataset consisted of N=60,128 observations of recruits born in European countries other than the Holy Roman Empire, which was analyzed in chapters 1 and 2. Since the soldiers enlisted in regiments that were in the service of the Kingdom of France, it was very likely that a minimum height requirement (MHR) existed for them, similar to the one identified in chapter 1 for German soldiers. Because recruits shorter than the MHR were not allowed to enlist, the sample at our disposal in an incomplete representation of the population, that is to say, the data is left-truncated. The econometric approach has to take this truncation into account, otherwise the estimated parameters will be inconsistent[5] (Wooldridge 2010). Because a MHR was not strictly enforced (Komlos 2004), we observe recruits below the actual MHR in our sample, but with a reduced frequency[6] compared to a sample that is not truncated (Komlos 2004). Thus, we first had to identify the correct truncation point of the variable height, the dependent variable in the regressions estimated in this chapter.

3.1.1. Minimum height requirement

Parallel[7] to the strategy we used in chapter 1, we identified the MHR for the dataset by means of visual inspections of histograms of heights. To the best of our knowledge, no literature exists that discusses the MHR being applied to foreign troops in service of the Kingdom of France. Consequently, we had to rely on literature that examines the MHR for Frenchmen for guidance.

We separated the sample by youth and adults, and recruits of the elite companies of Grenadiers received special consideration. To join the ranks of these special companies, a recruit had to exceed a higher MHR than ordinary soldiers (Corvisier 1968, p.83). We identified N=3,146 Grenadiers in the sample at hand. Komlos (2003) found that members of special troop companies[8] were taller compared to ordinary soldiers. A'Hearn's[9] (2003) regressions yielded a coefficient of 7.8 cm for a dummy variable for Grenadiers. Baten[10] (1999) estimated coefficients of Grenadier-dummies that ranged from 5.7 cm to 8.0 cm. The overall distribution of heights suggests a value of 62 Fi (167.8 cm) as the most likely MHR in effect in our dataset (figure 1).

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[5] This is in particular the case for OLS regressions (Wooldridge 2010).

[6] This phenomenon is also known as *"shortfall"* (Komlos 2004, p.161).

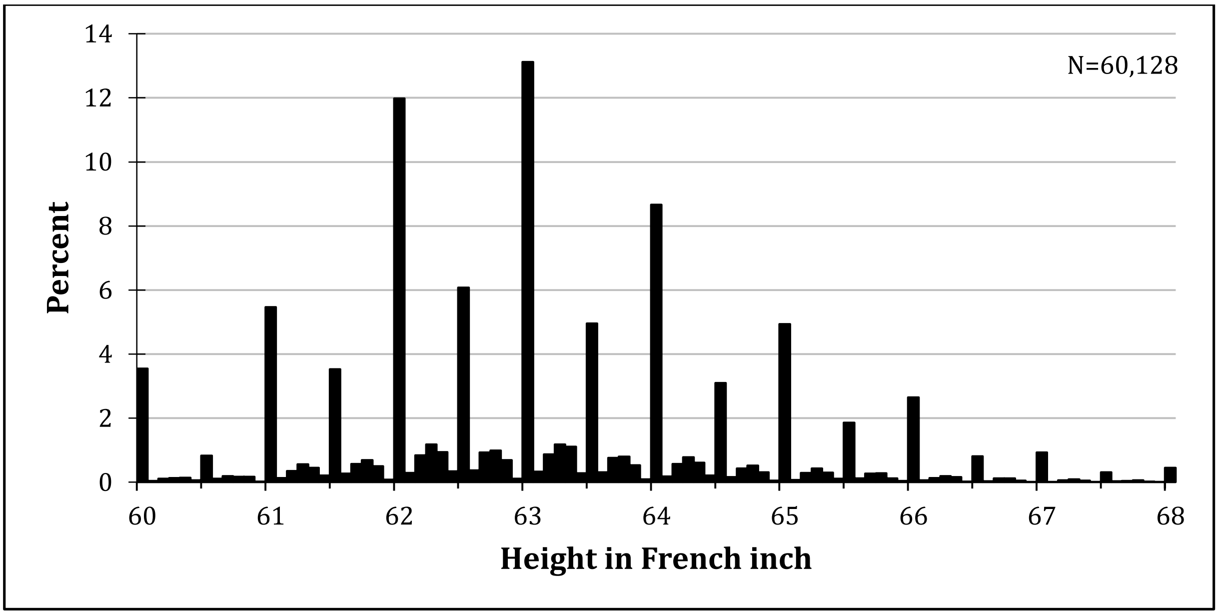
[7] The structure and content of this section are very similar to the discussion in chapter 1, These are unavoidable overlaps, since the chapter at hand is intended to be a self-contained article, so the reader should excuse the repetition.

[8] Komlos used a category "special troops" that contained other special companies and Grenadiers (Komlos 2003, footnote 16).

[9] Value was copied from: (A'Hearn 2003, p.364, table 2). The estimates were based on a restricted TNR. Note that A'Hearn studied soldiers in the Habsburg army, and we did not know how Grenadier companies differed in structure between the French and Habsburg armies.

[10] Value was copied from: (Baten 1999, p.177, table B1).

Figure 1: Distribution of heights



Sources: See the text. *Notes:* N=352 observations below 60 Fi (162.4 cm) and N=479 observations above 68 Fi (184.1 cm) are not shown.

When the sample was split between ordinary troops and Grenadiers, it became evident that a higher MHR was in effect for Grenadiers than for all of the other[11] soldiers (figure 2). Clearly, the MHR for ordinary soldiers was 62 Fi (167.8 cm). For Grenadiers, 63 Fi (170.5 cm) or 64 Fi (173.2 cm) were both possible values for the MHR.

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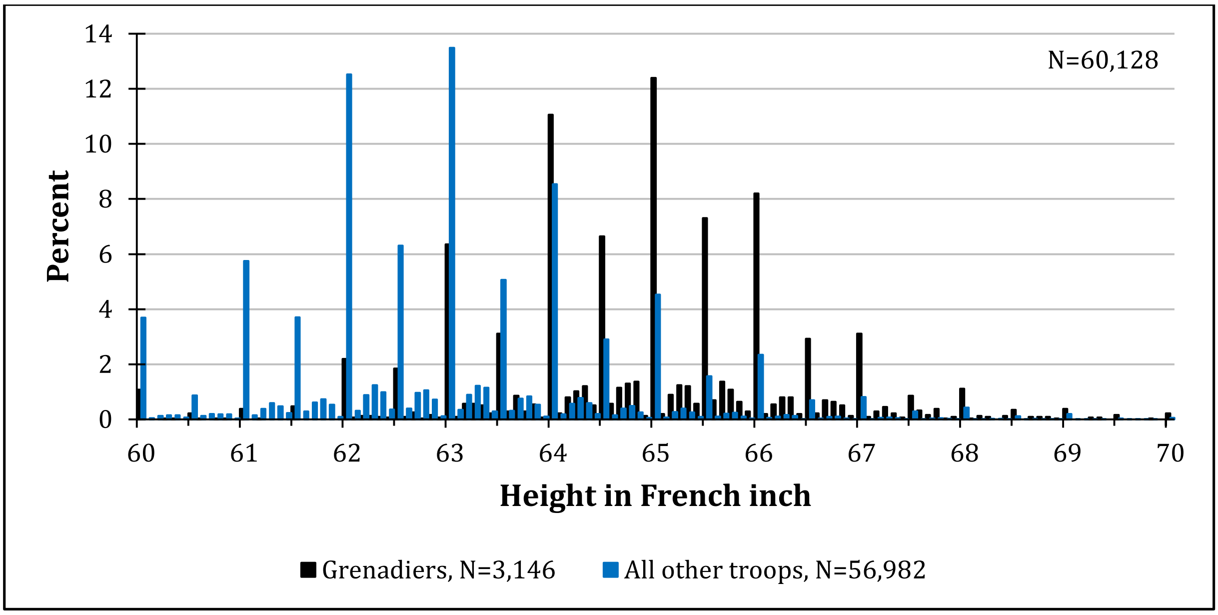
[11] This category also included members of other special companies (Colonelle, Lieutnant Colonelle and Chasseurs). We are not aware of a special MHR for these companies or of a discussion of such in the literature.

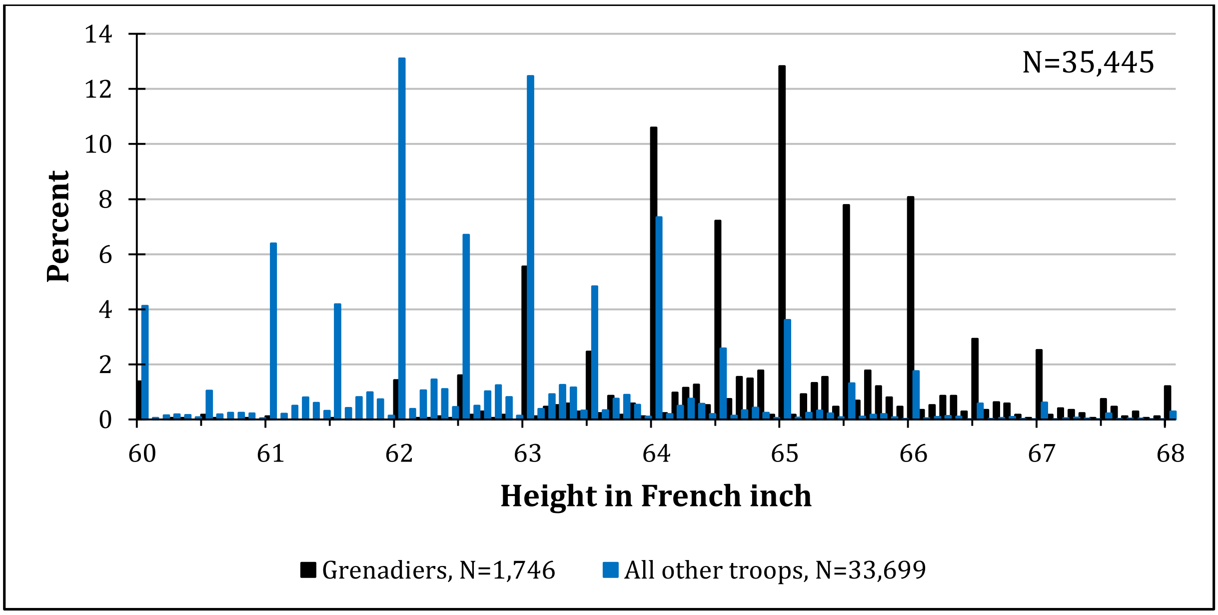
Figure 2: Distribution of heights, Grenadiers and all other troops



Sources: See the text. *Notes:* N=352 observations below 60 Fi (162.4 cm) and N=115 observations above 70 Fi (189.5 cm) are not shown.

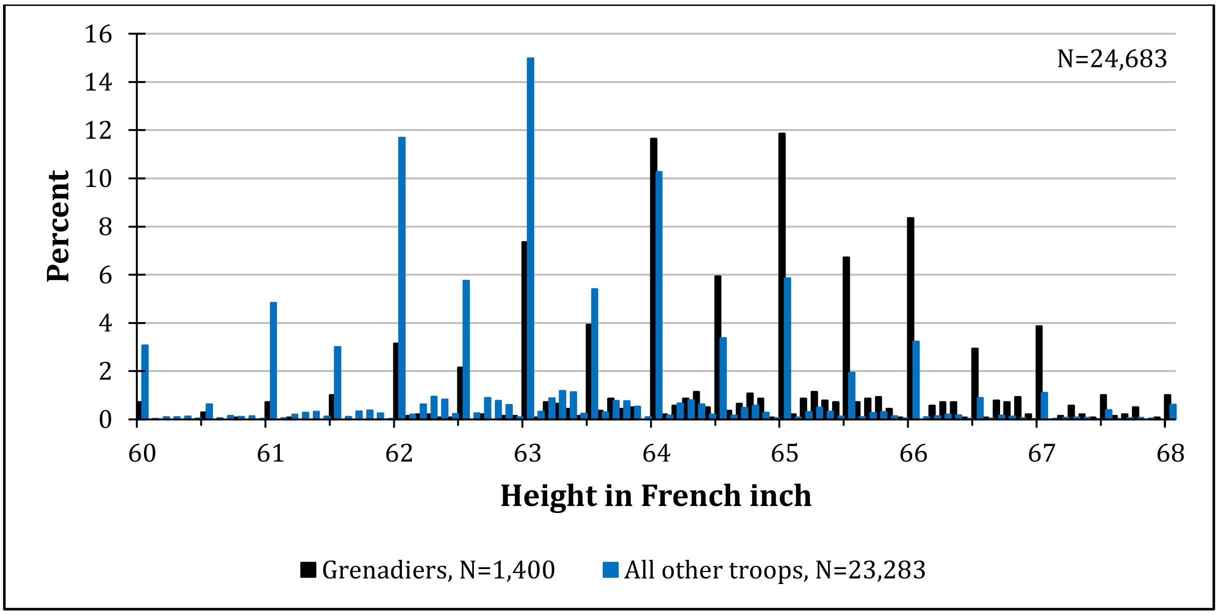
Next, we studied the distribution of heights for youth (16 to 23) and adults (24 to 50) separately, as suggested by Komlos (2004).

Figure 3: Distribution of heights, soldiers age 16 to 23



Sources: See the text. *Notes:* N=245 observations below 60 Fi (162.4 cm) and N=265 observations above 68 Fi (184.1 cm) are not shown.

Figure 4: Distribution of heights, soldiers age 24 to 50



Sources: See the text. *Notes:* N=107 observations below 60 Fi (162.4 cm) and N=214 observations above 68 Fi (184.1 cm) are not shown.

Two conclusions can be drawn from figures 3 and 4. Firstly, the MHR for ordinary soldiers was 62 Fi (167.8 cm), irrespective of their age. Second, recruits could enlist as Grenadiers provided that they were at least 64 Fi (173.2 cm) tall. While a MHR of 63 Fi (170.5 cm) for adult Grenadiers was also conceivable, a shortfall in the distribution was already visible at this value. In addition, we experimented with a MHR that varied between adult and youth Grenadiers, but the estimated coefficient of Grenadiers was not as plausible as when the same MHR for all Grenadiers was used.

Corvisier (1968) and Komlos (2003) distinguished between the MHR applied in times of peace and the MHR applied in times of war[12], but we found no evidence that the MHR was lowered in times of war (figures 5 and 6). This conclusion is further supported when we restrict our attention to enlistments during the War of the Austrian Succession or the Seven Years' War (histograms not shown).

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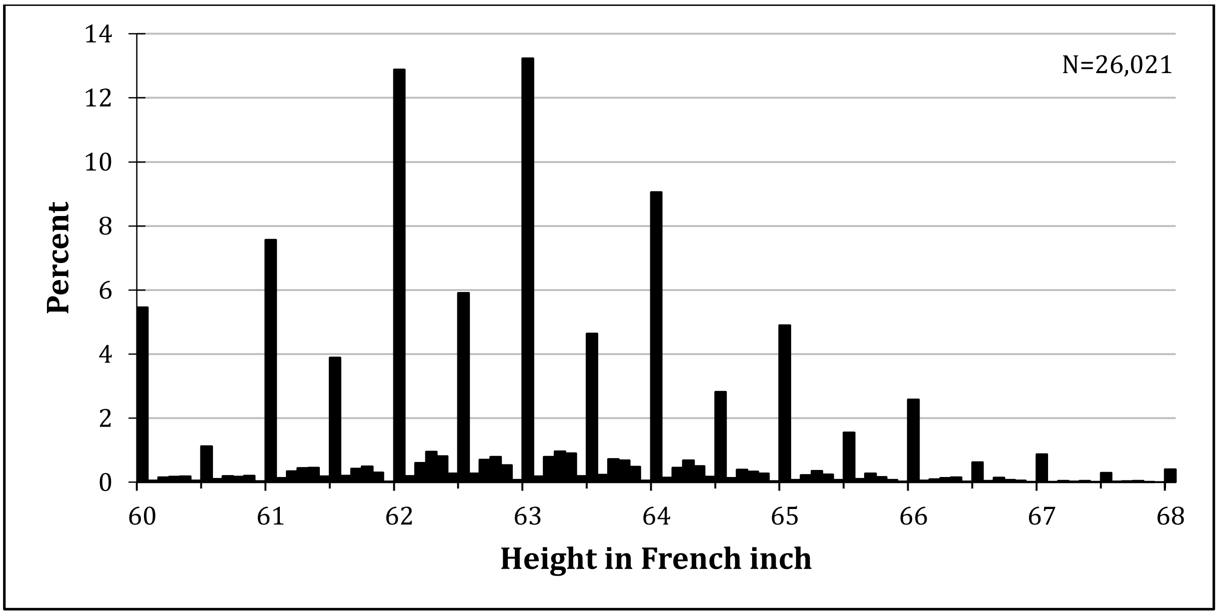
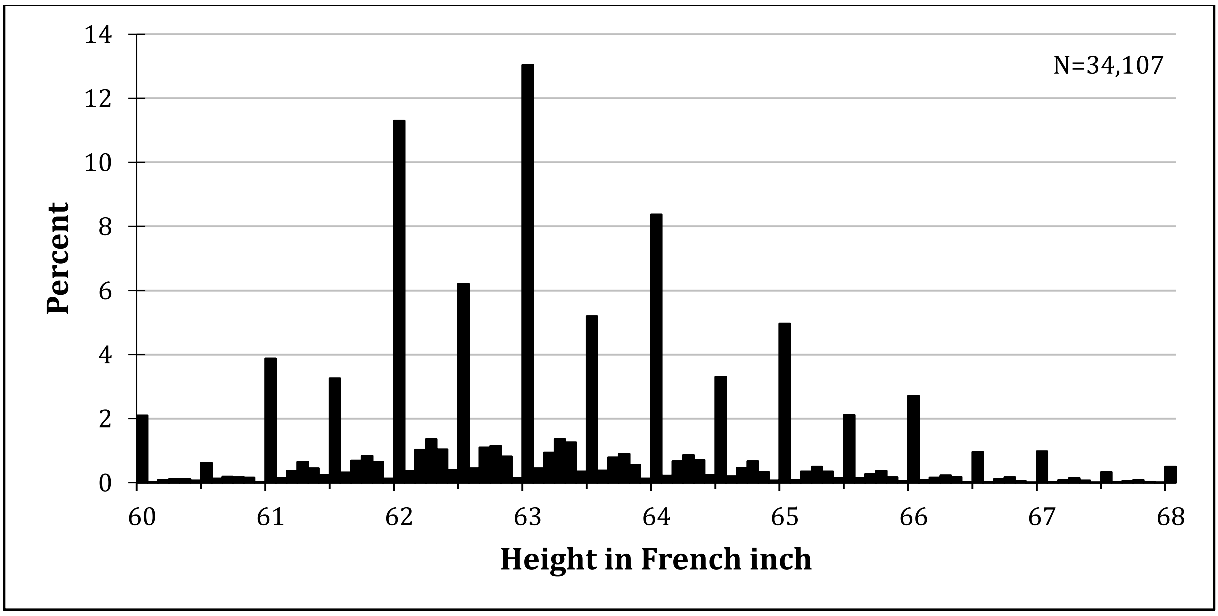
[12] The MHR during times of peace was 62 Fi (167.8 cm), lowered to 61 Fi (165.1 cm) when a recruit enlisted during times of war. Komlos (2003, footnote 13) added that a MHR of 60 Fi (162.4 cm) was plausible for recruitments during the War of the Austrian Succession.

Figure 5: Distribution of heights of soldiers who enlisted in times of war



Sources: See the text. *Notes:* N=279 observations below 60 Fi (167.8 cm) and N=152 observations above 68 Fi (184.1 cm) are not shown.

Figure 6: Distribution of heights of soldiers who enlisted in times of peace



Sources: See the text. *Notes:* N=73 observations below 60 Fi (167.8 cm) and N=327 observations above 68 Fi (184.1 cm) are not shown.

We investigated the distributions of heights separately for recruits from the British Isles, because the recruitment practices were different for non-continental soldiers. The recruitment practices that applied for them demanded special consideration: In the 17th century, refugees from Ireland enlisted in French Irish regiments, and in the first half of the 18th century, some recruiting took place in the Irish counties of Clare, Kerry and

Connaught, with subsequent smuggling into France (Chartrand 1997). Throughout the 1720s and 1730s, the recruitment was tolerated by the English, but became more difficult over time, resulting in almost no recruitment after 1745 (Chartrand 1997). Secret recruiting in Ireland was documented by Clarke de Dromantin (2005). He also stressed that after 1738, enlistment of the Irish in a foreign army without permission of the British Crown was punishable by death, and that the English parliament made a similar decision in 1746. Finally, Clarke de Dromantin (2005) noted that in 1756, the parliament decided that any subject of the British Crown enlisting with the French should face the death penalty.

These statements are consistent with what we observed in our dataset: 82.2% of all Irish recruits enlisted before 1746. Enlistments took place in the same regiments after 1745 as before, though after 1745, the percentage of Irish recruits enlisting in non-Irish regiments increased substantially. Our data contains recruits who enlisted in Sottish regiments of the French army. Chartrand (1997) reported that the Scottish regiments were created from Jacobite Scots who fled to France after their defeat at the Battle of Culloden in 1746. We observed the enlistment of Scottish recruits beginning in 1690, but in different regiments. 19.5% of Scotsmen in our sample enlisted before 1744, the year when the French foreign regiment "Royal Ecossais[13]" was created (Corvisier 1970). Previously, enlistments took place in Irish regiments that had already been established beforehand. This is consistent with (Clark de Dromantin 2005), who argued that since 1690, recruits from the British Isles serving in France enlisted primarily in Irish regiments. But after 1743, the vast majority of Scotsmen in our data enlisted in the Scottish regiments. Most Englishmen enlisted in Irish or Scottish regiments. In addition, only Catholics could enlist in Scottish or Irish regiments (Chartrand 1997). As a result, it is unlikely that the Englishmen and Scotsmen we observed were representative of the general English and Scottish population. English deserters could enlist in Irish regiments during times of war when they claimed to be Catholic (Chartrand 1997). Yet, this fact is insufficient to alleviate our concerns with respect to the sample selection for the English. Clarke de Dromantin (2005) noted that in times of war, subjects of the British Crown who were unemployed and residing in France and unemployed were required to join an Irish regiment.

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[13] "Ecossais" means "Scottish" in French.

Given this unusual recruitment practices for recruits from the British Isles, we analyzed the distributions of heights separately for these recruits, and additionally for different periods of enlistment: We inspected the distributions for Irish recruits separated by enlistment before and after 1745, taking into account the increasing difficulty of recruiting. In respect to the English and Scottish heights, we separated the distributions by enlistments before and after 1744.

We found no supporting evidence for the conclusion that the MHR was different for recruits from the British Isles than for recruits from continental Europe, nor did we detect a variation in the MHR over time. We also found no evidence that the MHR was lowered in times of war[14] for non-continental recruits. However, this does not imply that the issue of representativeness is resolved, because the recruitment practices for the recruits from the British Isles could still attract certain strata of the population, given that they were sufficiently tall.

Observations below the specified MHRs were eliminated from the dataset (N=12,022), as well as N=7 recruits taller than 73 Fi (197.6 cm), because taller height are implausible. Since we estimated trend in stature using observations for a dataset that contained adults and youth, we had to eliminate all observations with years of birth after 1762 (N=1,672), the last year where we observed adult[15] recruits. The working dataset now consists of N=46,427 observations.

3.1.2. Econometric methodology

We estimated trends in stature using two methods: Truncated Normal Regression (TNR), and GAMLSS[16] (Rigby and Stasinopoulos 2005, 2007). All models relied on the assumption of a normally distributed dependent variable, and heights do indeed follow a normal distribution (Bogin, 1999). Furthermore, the regression techniques took into account the truncation of the dependent variable. In the conventional approach, both estimators also provide an estimate of the standard deviation of the dependent variable. However, in the height literature, a special version of the TNR is widely used: A'Hearn (2004) proposed estimation of TNR models where the standard deviation of the dependent variable is

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[14] These histograms are available upon request.

[15] Otherwise, our predictions would contain out of sample predictions.

16 "Generalized Additive Model of Location, Scale and Shape". The existence of the GAMLSS was pointed out to us by Fabian Scheipl and Helmut Küchenhoff.

fixed[17] a priori and not estimated, since this can increase the accuracy of the estimation. We extended this approach by also estimating a GAMLSS where we fixed the standard deviation prior to estimation of the other parameters. Such models are designated "constrained" throughout this chapter.

TNR were combined with dummy variables for birth cohorts (among other controls) to model the secular trends in height. GAMLSS differed in this aspect. No functional form was assumed for the time trend. Instead, the trend was estimated flexibly[18] ("smoothed") from the data. In a regression that involves smoothing, the variability of the estimated trend is controlled by the smoothing parameter. As in chapters 1 and 2, we selected the parameter automatically using generalized cross-validation (Hastie and Tibshirani 1990, Rigby and Stasinopoulos 2005). When necessary, we excluded early years of birth from the spline regressions because spline estimates reacted sensitively to a low number of observations per year, a phenomenon that pertains to early years of birth.

All estimations were conducted with height in French inch as the dependent variable. The ongoing growth process of youth is reflected by the inclusion of dummy variables for ages below 24. Where possible, we included controls for regions respectively territories[19] within a given country. Since the inclusion of a dummy for enlistment during war in the regressions in chapters 1 and 2 yielded convincing results, we pursued the same strategy.

Predictions of height were based on the following principles: Age controls received a weight of zero. The coefficients of all other dummy variables were weighted by their respective sample proportions. Regression results and predicted heights were converted into cm (1 Fi = 2.706667 cm[20] for visualization and the depiction of regression results.

We considered using clustered standard errors, but except for France[21], we did not have enough clusters to ensure that these standard errors were reliable. Instead, we used heteroscedasticity-robust standard errors.

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17 The value is usually fixed to the modern day value of 6.86 cm. We convert the standard deviation to French inches for the estimation: 2.534482446 Fi (6.86 cm/2.706667 Fi by cm) and use the rounded value of 2.534 Fi in all constrained regressions.

[18] The flexible component was modeled using a penalized spline of degree 2.

19 For example, historical provinces of France.

20 (Komlos 2003, footnote 5).

21 We had 39 clusters for France and substantially fewer for the other countries. Angrist and Pischke (2009) suggested a minimum of circa 40 clusters for a reasonable application of cluster-robust errors. In any case, the choice of a specific standard error estimate has no influence on the estimated coefficients but only affects the estimated standard error of the estimates.

3.2. Descriptive statistics

Frenchmen constituted the majority of recruits, followed by a substantial number of recruits from Italy and Ireland (table 1). Fewer recruits were born in Switzerland, England[22] and Scotland, but the number of observations for these countries was sufficiently high to estimate trends in stature. For Spain[23], the United Provinces [24], Hungary and Corsica we only estimated the mean stature for two time periods. We discarded recruits from countries collected in the category "other" in table 1, since the countries in this group were too heterogeneous. Occupational information was not available for a sufficiently large number of observations, neither for the soldiers' occupation[25] (96.5% missing), nor for his father's occupation[26] (92.4% missing). Information concerning the religion[27] of recruits is virtually unavailable (95% missing).

Table 1: Descriptive statistics

	N	Percent
Country of birth		
France	23,560	50.8
Italy	8,485	18.3
Ireland	6,060	13.1
Switzerland	2,695	5.8
Scotland	1,493	3.2
England	1,356	2.9
Spain	698	1.5
Netherlands	654	1.4
Hungary	515	1.1
Corsica	333	0.7
Other	578	1.2
Decade of birth		
1642-1669	359	0.8
1670-1679	796	1.7

Table continues on the next page

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[22] Including Wales.

[23] Excluding the Spanish Netherlands who were analyzed in chapters 1 and 2.

[24] Approximately corresponds to today's Netherlands. We designate them "Netherlands" throughout the paper.

[25] Occupational categories were based on HISCO (van Leeuwen et al. 2002) with own extensions where no HISCO category applies. Production and related: 2.3%, "Sans vacation" (An ambiguous category. The term may mean "unemployed" or "does not need to work". See the data appendix for details.): 0.5%, Laborer: 0.2%, Agricultural: 0.2%, Service: 0.2%, Professional, technical and related: 0.1%, Other (Bourgeois, Sales, Clerical and related, Student, Administrative and managerial combined): 0.1%.

[26] Production and related: 3.6%; Laborer: 1.8%, Agricultural: 0.8%, Sales: 0.5% Service: 0.4%, Bourgeois: 0.3%, Professional, technical and related: 0.2%, Other (Clerical and related, Administrative and managerial, disabled person, "Sans vacation", retired or private Gentleman combined): 0.1%.

[27] Given it was recorded, 3.7% were Catholics and 1.2% were not Catholics. A more detailed breakdown of the non-Catholics is available upon request.

Table 1, continued

	N	Percent
Decade of birth		
1680-1689	1,938	4.2
1690-1699	4,133	8.9
1700-1709	5,640	12.2
1710-1719	7,146	15.4
1720-1729	8,478	18.3
1730-1739	5,697	12.3
1740-1749	5,134	11.1
1750-1759	5,964	12.9
1760-1762	1,142	2.5
Age at enlistment		
16 to 23	25,545	55.0
24 to 50	20,882	45.0
Decade of enlistment		
1671-1699	414	0.9
1700-1709	468	1.0
1710-1719	4,218	9.1
1720-1729	5,152	11.1
1730-1739	6,018	13.0
1740-1749	9,101	19.6
1750-1759	6,967	15.0
1760-1769	6,025	13.0
1770-1779	5,842	12.6
1780-1786	2,222	4.8

Sources: See the text. *Notes:* Results were rounded to one decimal place.

3.3. Mean height of recruits born in countries with a low number of observations

We first documented the height of recruits born in countries where the available number of observations did not permit the estimation of trends in stature. We estimated the mean height using constrained and unconstrained truncated regressions for Spain, the Netherlands, Hungary and Corsica. We added a dummy variable to each regression that took the value 1 for all soldiers born after the respective median year of birth[28].

Predictions based on unconstrained regressions were not very precise: The estimated confidence intervals were very wide (figure 7). Therefore, we focused on the constrained estimates (figure 8) when interpreting the results. Mean heights were lower for all countries compared to the unconstrained regressions. Heights increased in the

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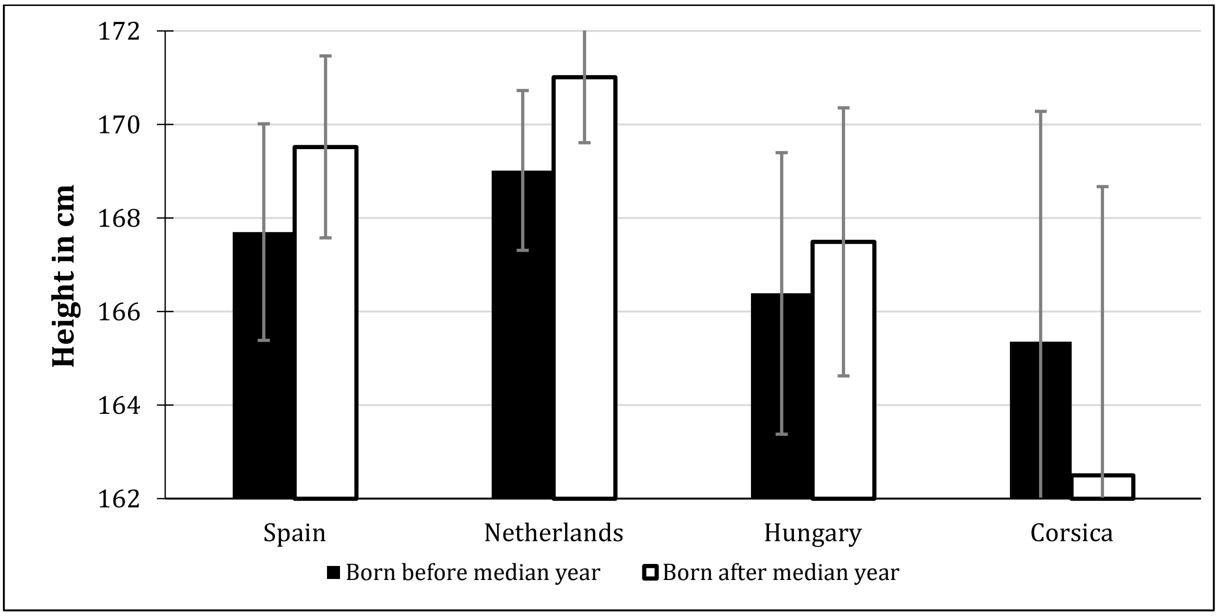
[28] The median years of birth are 1727 for Spain and the Netherlands, 1722 for Hungary and 1726 for Corsica.

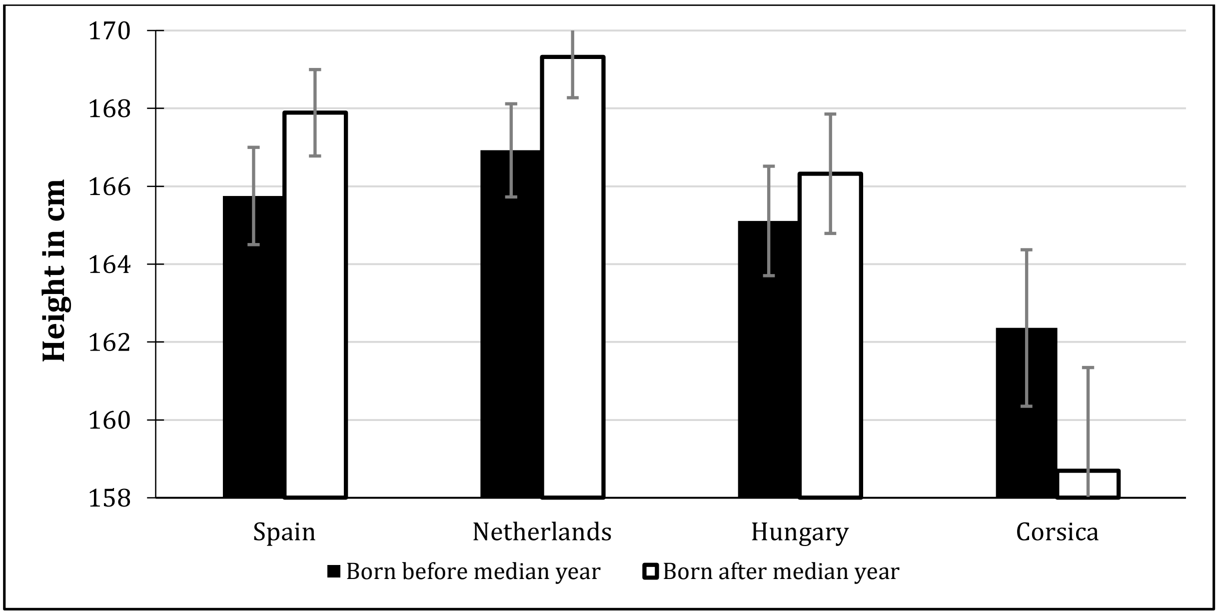
Netherlands and Spain, but stagnated in Hungary and declined substantially in Corsica (figure 8). Based on the confidence intervals of the predictions, the Dutch were as tall as the Spanish before 1727, but grew taller afterwards. The Corse people were always the shortest.

Figure 7: Estimated height of soldiers born in Spain, the Netherlands, Hungary and Corsica, unconstrained estimates



Sources: See the text. *Notes:* Grey bars indicate the 95% confidence interval of predicted heights. The upper bound of the confidence interval of the Netherlands is 172.4 cm (not shown). The lower bounds of the confidence interval for Corsica are 160.4 cm and 156.3 cm respectively (not shown).

Figure 8: Estimated height of soldiers born in Spain, the Netherlands, Hungary and Corsica, constrained estimates



Sources: See the text. *Notes*: Grey bars indicate the 95% confidence interval of predicted heights. The upper bound of the confidence interval of the Netherlands is 170.4 cm (not shown). The lower bound of the confidence interval for Corsica is 156.1 cm (not shown).

The oldest Hungarians in Komlos' (1989) study were born in the 1730s, measuring[29] 167.2 cm, a value that lies within the prediction-confidence interval based on the constrained regression for those born after the median year, but is higher[30] than what is estimated based on a constrained regression for earlier years of birth. For the other countries, virtually no evidence exists for the 18th century: Cámara (2009) estimated means in stature for two communities in Andalusia, but in one case he could only report the mean of those recruits who were taller than a threshold. Standardized at age 21, recruits born in Santa Fe between 1777 to 1815 were 167 cm[31] tall, given that they were taller than the 162.4 cm. For the second community, Cámara estimated heights of all recruits. Standardized mean heights[32] ranged between 163.3 cm (1735-1745) and 164.3 cm. Drukker's and Tassenaar's (2000) estimates of Dutch heights began in the 19th century[33], with levels of 161.7 cm[34] for 19 ¾ -year old males conscripted in 1821. These results, however, do not challenge our own results, but instead provides faint evidence that the decline in European stature in the second half of the 18th century did not exclude the Dutch. To the best of our knowledge, no estimates exist for Corsica in the literature that we can compare our results to.

3.4. Secular trends in stature of European countries

3.4.1. France

We augmented[35] our dataset of N=23,560 Frenchmen with N=23,557 observations used by Komlos (2003). Our constrained regression results[36] corroborate his findings. Frenchmen were very short in the 17th century (below 162 cm), then experienced an improvement in the nutritional status that lasted until the second half of the 18th century,

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[29] Values were copied from: (Komlos 1989, p.57, table 2.1), Adult soldiers, QBE estimates.

[30] Komlos' estimate of 166.3 cm for recruits born in the 1760s is closer to our estimate for recruits born after 1722. The years of birth are unevenly distributed in our Hungarian sample: 15% of all recruits were born after 1754, but only 10% were born between 1739 and 1754.

[31] We read off the values from: p.51, figure 1, so they should be considered approximations.

[32] We read off the values from: p.55, figure 6, so they should be considered approximations.

[33] See (de Beer 2004) for evidence on Dutch heights based on skeletal remains. Between 1600 and 1800, Dutch people with an average SES were between 168 cm and 170 cm tall.

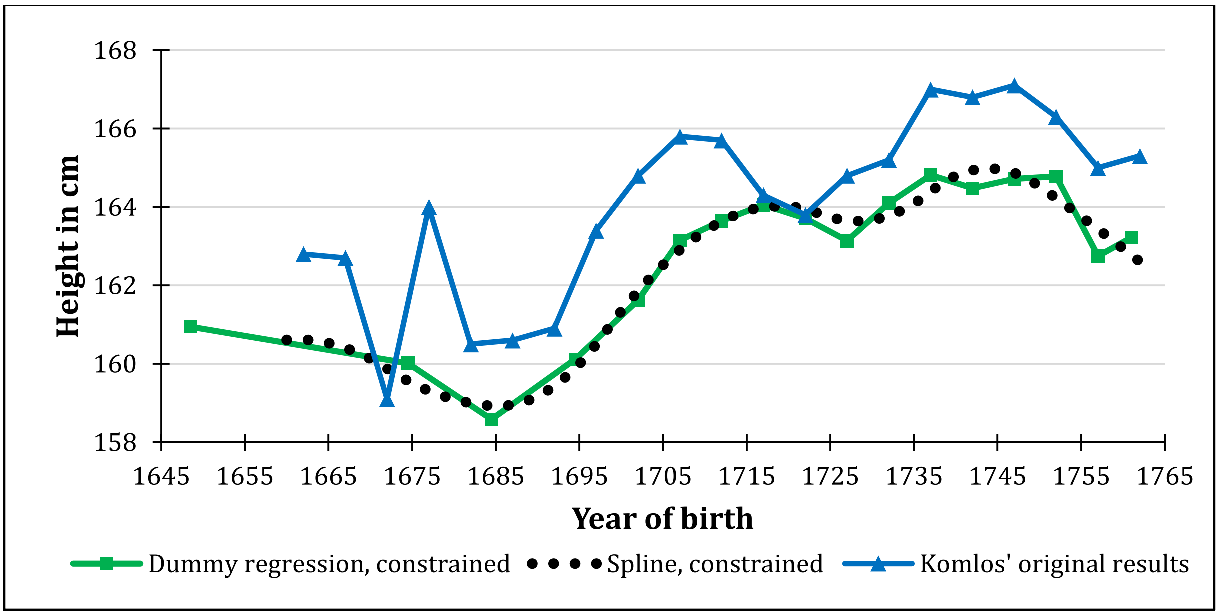
[34] Value copied from: (Drukker and Tassenaar 2000, p.90, appendix 1, column 2).

[35] We are indebted to John Komlos for providing us with his coded data, allowing us to easily combine both datasets without major re-coding. His dataset was treated in the same way as our data with respect to the definition of the MHR, and in respect to other observations that were eliminated from this dataset for other reasons.

[36] Trends based on constrained dummy regression estimates were on average 0.7 cm above the trends based on the unconstrained dummy regressions while both trends moved in parallel. Thus, we only depicted the trends based on the constrained dummy regression. The same applies to unconstrained spline regressions.

when heights started to decline again (figure 9). Trend estimates based on constrained spline estimates followed a similar pattern. However, we had to select the smoothing parameter manually[37] as the automatic procedure yielded estimates with an implausibly high short-term variation in stature. The fact that our estimates are below Komlos' (2003) original results, may be a result of the difference in estimation techniques between our study and Komlos'. The estimated trends were qualitatively identical when we only used our newly digitized data, excluding Komlos' data (results not shown).

Figure 9: Predicted height of recruits born in France



Sources: See the text. Komlos' original results: Komlos[38] (2003). *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Constrained spline regression was restricted to years of birth after 1659.

3.4.2. Italy

Long-term trends in Italy followed a path of increasing heights, but overlapped with short-term cyclical fluctuation in stature, with a cycle length of circa 10 years[39] (figure 10). Spline estimates closely followed the dummy variable trends, except in the constrained case where heights fluctuated little more for early years of birth. The regressions were based on N=8,485 observations and included dummies for territories within Italy.

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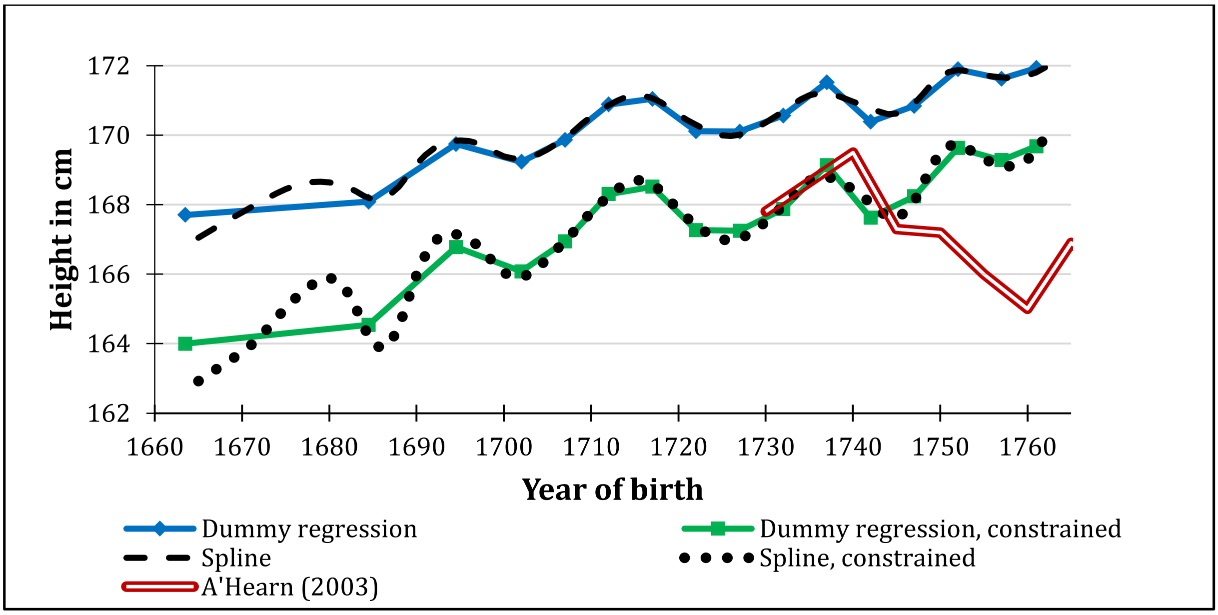
[37] The number of knots was set to 8.

[38] We read off the values from: (p. 170, figure 3: "Quinquennial height estimates, adults"), so they should be considered approximations.

[39] Such cycles were also identified for Habsburg soldiers in Woitek (2003). He used Komlos' (1989) data, so Italian possessions of the Habsburgs were not included.

Figure 10: Predicted height of recruits born in Italy



Sources: See the text and A'Hearn[40] (2003). *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort. Spline regressions were restricted to years of birth after 1664.

A'Hearn (2003) documented the trajectory of heights for Northern Italy. The vast majority of our Italian recruit were also born in the northern part[41] of Italy[42]. Thus, we could compare[43] our estimates to A'Hearn's (2003) estimates. Our results were well matched to A'Hearn's estimates for the time period 1725 to 1745 (figure 10). Afterwards, our estimates deviated from his estimates. He predicted a continual decline in stature, while in our sample, heights increased again and stagnated[44] after 1750. We interpret this stagnation as a faint indication that Italy was not spared from the phenomenon of deterioration in the nutritional status that is documented throughout Europe. Our results[45] were qualitatively unaffected when we restricted the observations to northern Italy or when we additionally discarded recruits born in Savoy. Furthermore, when we

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[40] We read off the values from: (A'Hearn 2003, p. 371, figure 6), so they should be considered approximations. Note that we assigned the value for the first cohort that A'Hearn designates "before 1740" to the year 1730.

[41] N=4,013 in Savoy-Piedmont, N=606 in the Republic of Genoa, N=430 in the Duchy of Milan, N=375 in the Republic of Venice and N=143 in the Duchy of Parma and Piacenza.

[42] But note that Savoy was also included in our data. Today it is part of France, but before 1860, it was part of Savoy-Piedmont (Köbler 2007).

[43] Since A'Hearn (2003) used the constrained TNR, we compared his findings to our results based on constrained regressions.

[44] The differences in coefficients for birth cohorts after 1750 were not statistically different from one another.

[45] Based on the same regression specification as the main result.

restricted our sample to recruits born after 1739, and added a dummy variable for the birth cohort 1750 to 1762[46], we found a significant and positive effect[47].

3.4.3. Switzerland

N=2,658 observations[48] were available to analyze[49] Swiss heights. The nutritional status of the Swiss remained largely constant[50] in the 17th century, until the Swiss enjoyed a short lived amelioration of the nutritional status in the first decade of the 18th century, followed immediately by a decline. Afterwards, the nutritional status improved considerably after the third decade of the 18th century. Heights declined again in the second half of the 18th century (figure 11). The pattern of a decline in the 1720s, followed by a subsequent recovery and another decline in the 1750s is similar to the pattern we documented for the Holy Roman Empire that bordered Switzerland to the north and east. Spline regressions implied a growth in stature from the 17th century to the first decade of the 18th century, but we could not assess the significance of the trend in a spline regression in a matter comparable to the dummy regressions. Note that decline in stature in the 1750s is less pronounced compared to the Holy Roman Empire, and the level of heights in relatively high in general.

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[46] This split the sample into groups of 1,312 and 1,942 observations respectively.

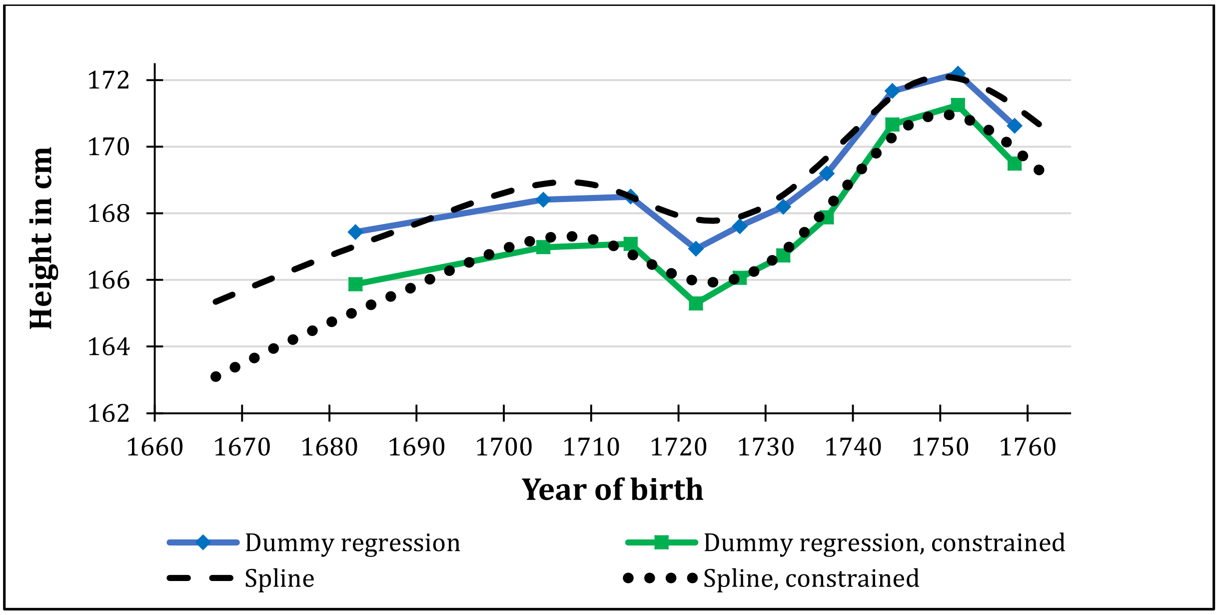
[47] This holds in all regression specifications: Whether all controls were included or not and in constrained as well as unconstrained regressions.

[48] We excluded soldiers enlisted in the special companies “Light Troops” since the number of observations is too low for this group (N=37).

[49] We did not have a sufficient number of observations for every canton, but we divided Switzerland into an eastern and western region, both represented by dummies. Furthermore, we added a dummy variable for those recruits where the region of birth was unknown.

[50] Estimated coefficients for birth cohorts 1667 to 1699, 1700 to 1709, 1725 to 1729 and 1730 to 1734 are not significantly different from zero. The coefficient of the birth cohort 1710 to 1719 is positive and significant at 10%. Reference category is the birth cohort 1720 to 1724. All birth cohort coefficients after 1734 are significant at least at 5%.

Figure 11: Predicted height of recruits born in Switzerland



Sources: See the text. *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

To the best of our knowledge, 17th and 18th century Swiss heights have previously been unstudied. The earliest estimates of Swiss heights are those of Edouard Mallet[51] documented by Staub et al. (2011) that pertained to Genevan conscripts approximately 21 years of age. The oldest recruits in this sample were born in 1805. Staub et al. (2011) provided a frequency distribution of heights for recruits born 1805 to 1814. The average height was 167.7 cm, a value that is plausible given the level of heights we estimated combined with a hypothesized long-term decline in Swiss stature.

3.4.4. Ireland

Our sample contained N=6,060 recruits born in Ireland[52]. Contrary to the previous subsamples, we did not observe many recruits born after 1730 (only 3.1% of all Irish recruits). Thus, we had to define a single birth cohort dummy for all years of birth from 1730 to 1760. We did not estimate[53] a spline regression since the years of birth exhibit

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[51] Mallet, Edouard. 1835. "De la taille moyenne de l'homme dans le Canton de Genève", Geneva. All results we refer to were taken from (Staub et al. 2011), and not from Mallet's original study.

[52] We did not observe a sufficient number of recruits to include a dummy for every Irish county in the regressions. Instead, we included a dummy for each of the provinces of Ireland (Connacht, Leinster, Munster and Ulster). In addition, we included a dummy for those recruits where the province of birth was unknown.

[53] We tested a substantial number of spline specifications, but none produced convincing results. Neither did the exclusion of early and late years of birth (with few observations per year) improve results, nor did the manual selection of the smoothing parameter. Most specifications led to an estimated decline in stature from the 1660s to the 1680s of circa 6 cm, which is implausibly large. Note that the dataset contained N=384 observations for the years 1660 to 1680, so the results were not an artifact of a low number of observations.

gaps on both sides of the interval studied and the corresponding numbers of observations at both ends of the year of birth interval was low. We estimated trends based on birth cohorts that spanned a minimum of 10 years. The distribution of years of birth would permit the use of 5-year birth cohorts in some cases, but predicted heights showed cyclical fluctuation[54] that we considered too high when such cohorts were used.

Our results provided faint evidence that Irish recruits were relatively tall[55] in the middle of the 17th century[56], and experienced a cyclical variation of the nutritional status afterwards, but at a comparatively high level of heights (figure 12). From the 1720s on, heights stagnated at the levels attained at the beginning of the 18th century, as none of the estimated coefficients for birth cohorts after 1719 is significantly different from zero[57]. Average heights for the birth cohort 1730 to 1760 were compatible[58] to Koch's estimates of Irish heights, as well as to some of Komlos and Cinnirella's (2007) estimates.

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[54] Results with 5-year birth cohorts are available upon request. We are not concerned by the cyclical nature of the trends, as height cycles with a length up to five years (in addition to a 10-year cycle) were identified by Woitek (2003). We did not consider our results to be convincing because of the amplitude of the fluctuations. In the 5-year birth cohort specification, heights exhibited a variation of 1 cm over five years in some birth cohorts. Such a short-term variation is implausibly large. In particular, between 1705 and 1729, the 5-year change in height was substantial and not uniform. All of the following statements refer to 5-year periods and coefficients from corresponding constrained regressions: Heights first decreased by 1.5 cm, increased again by 1.1 cm, then remained relatively constant for five years, then declined again by 1.3 cm and finally increased by 1.2 cm.

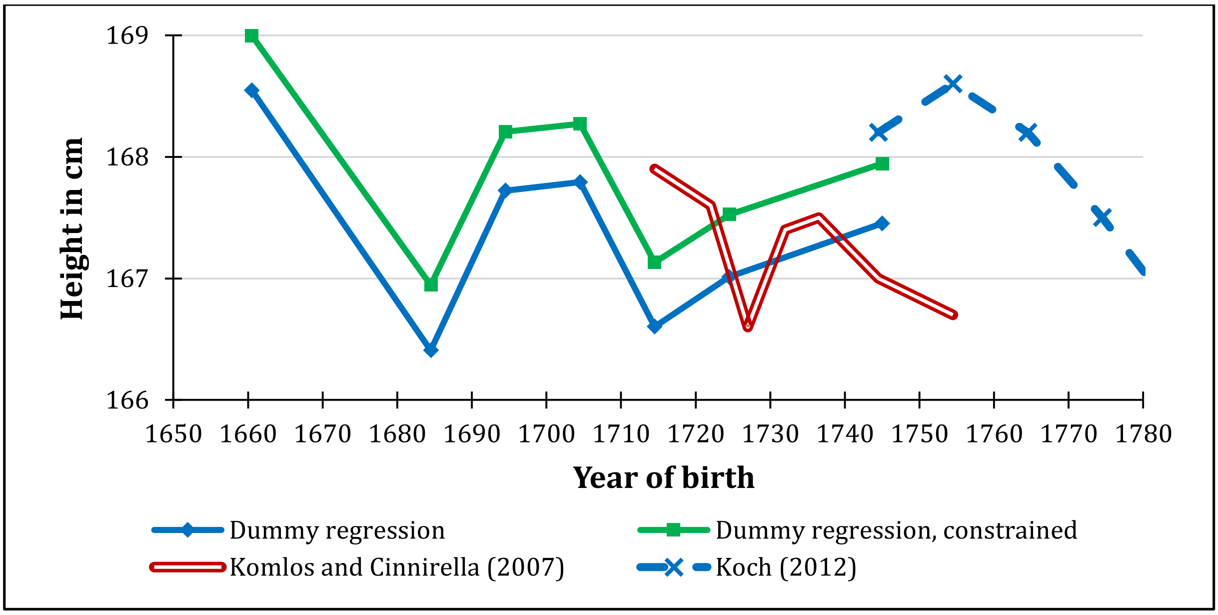
[55] The 95% confidence interval associated with the prediction was very wide, so a clear statement was not possible.

[56] The first birth cohort used in the regression spanned the years 1642 to 1679.

[57] The reference birth decade was 1700 to 1709.

[58] Since the last birth cohort dummy was not significant, the estimated height is even closer to Koch's (2012) estimate.

Figure 12: Predicted height of recruits born in Ireland



Sources: See the text and Komlos and Cinnirella[59] (2007), Koch[60] (2012). *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

3.4.5. England

Our analysis on English heights was based on N=1,356 observations. Due to the skewed distribution of years of birth, the final birth cohort had to cover the years from 1725 to 1762 to ensure a sufficient number of observations was contained in this category[61]. Constrained and unconstrained estimates were nearly identical (figure 13). English heights increased from the 17th century on, and declined after the first decade of the 18th century. However, the total change in heights was very small and except for the coefficient of birth cohort 1705 to 1719, none of the estimated birth cohort coefficients was significantly different from zero[62], although each dummy represented at least 200 observations. It is noteworthy that the coefficient of the dummy for enlistment during war was positive, contrary to the regressions pertaining to other countries[63]. Our results were compatible to Komlos' and Cinnirella's (2007) results based on European recruits serving in North America[64] (figure 13) in terms of the estimated levels. Interestingly, the unconstrained and constrained spline regressions differed. The unconstrained spline

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[59] We read off the values from: (p.280, figure 6, "Ireland MHR"), so they should be considered approximations.

[60] We read off the values from: (p.23, figure 3), so they should be considered approximations.

[61] 75% of all recruits in this cohort were born before 1735.

[62] The reference category were recruits born 1720 to 1724 (N=216).

[63] Results were qualitatively identical when this dummy was discarded from the regressions.

[64] The authors considered the magnitude of the decline they estimated in the 1720s to be implausible.

regression yielded a straight, upward sloping line, and the constrained spline also implies a long-term upward-trend, it exhibits slightly more short-term variation[65].

Our results were remarkably well matched to Floud et al.'s (1990) estimates for the 1740s. However, our spline estimates did not imply a strong upward trend after the 1750s, incompatible with the steep increase in stature estimated by the aforementioned authors. The average estimated height between 1760 and 1762 in the constrained spline regression was 168.0 cm, compared to Floud et al.'s (1990) 169.8 cm estimated for the first five years of the 1760s. Komlos and Küchenhoff (2012) argued that the estimates by Floud et al. (1990) were downward biased in the 1740s, since the sample was based on a subset of relatively short marine recruits. Thus, given the sample selection issue we identified for our sample of English recruits, the similarity of our results to Floud et al.'s (1990) estimates came as no surprise. Selection may also explain why our results did not match the more reliable[66] estimates of Komlos and Küchenhoff (2012).

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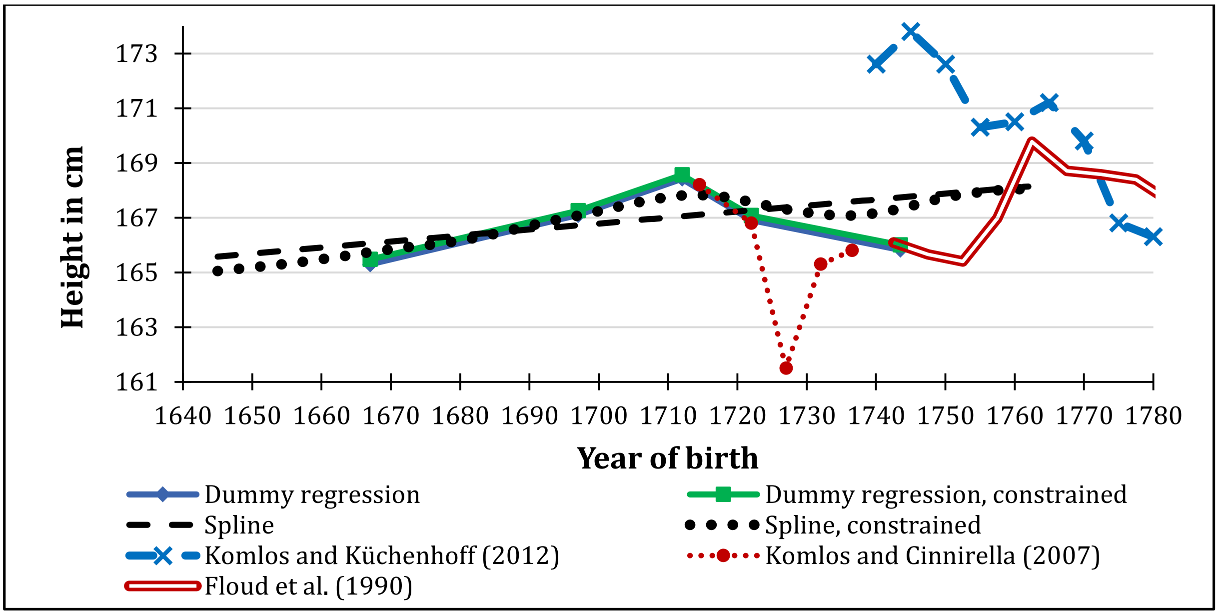
[65] Note that in the unconstrained as well as constrained spline estimations, the respective smoothing parameter was selected automatically.

[66] In the regression section, we present evidence that English heights did not react consistently to the variation in the price of wheat. We interpret this as yet another piece of evidence that our sample of the English is not representative.

Figure 13: Predicted height of recruits born in England



Sources: See the text and Komlos and Küchenhoff[67] (2012), Komlos and Cinnirella[68] (2007), Floud et al.[69] (1990). *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

3.4.6. Scotland

Estimates of trends in stature for Scots were based on 1,493 observations. The distribution of years of birth was even more skewed than for English recruits, so the last birth cohort ranged from 1735 to 1752, and contained only N=75 observations. Yet, the estimated coefficient for this birth cohort was of reasonable magnitude, so we decided to retain this dummy and the respective observations in the regressions. The dummy for enlistment during times of war was again positive and significant[70]. The estimated coefficients of birth cohort dummies implied a long-term downward trend in stature (figure 14), but none of these coefficients was significant. Given this, it could only be concluded that heights in Scotland stagnated. Spline regressions did not convey additional information: In constrained as well as unconstrained spline regressions, the smoothed trend in stature was a downward-sloping straight line (not shown).

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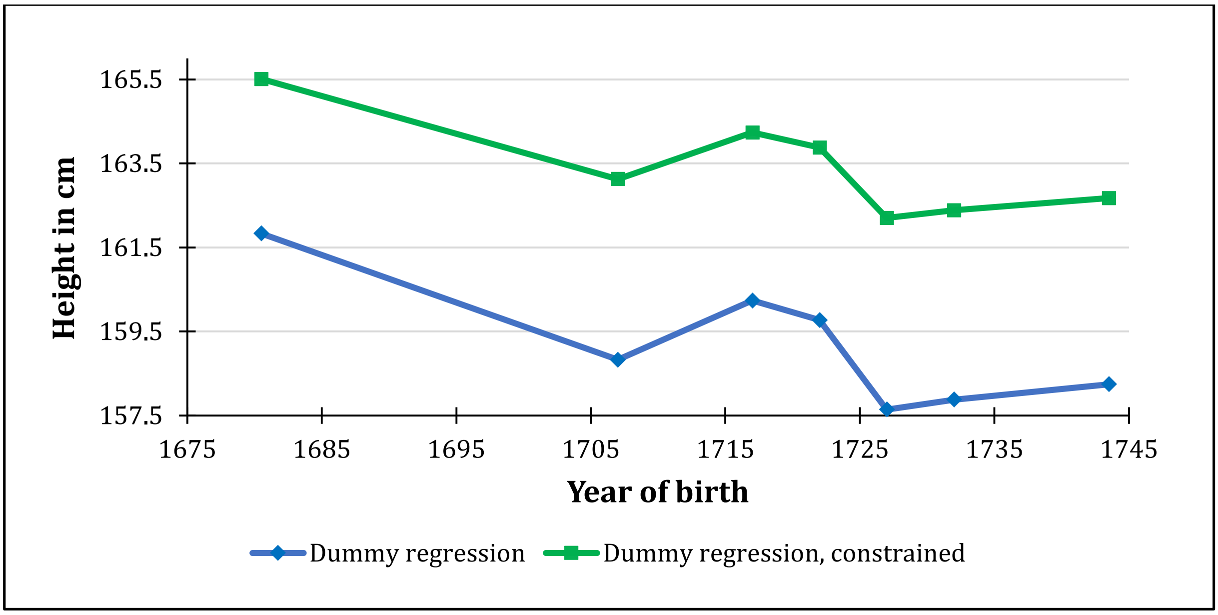
[67] We read off the values from: p.51, figure 1: “Army and Marines, MHR 66 unconstrained”, so they should be considered approximations.

[68] We read off the values from: p.280, figure 6: “England MHR”, so they should be considered approximations.

[69] Floud et al 1990, p.148, table 4.1: “Mean height, Age 24-29”.

[70] Excluding this dummy from the regression did not qualitatively alter our results.

Figure 14: Predicted height of recruits born in Scotland



Sources: See the text. *Notes*: The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

Our results are in contrast to Koch's (2012) estimates. He estimated Scotsmen to be much taller, circa 172.0 cm[71], in 1750, while we estimated a maximum height of 162.7 cm for the birth cohort 1735 to 1752. As was the case with our findings for the English, it is very likely that sample selection processes drove our results. Koch's (2012) results were based on British military records, but as previously discussed, the enlistment process for Scottish and English recruits serving the French King was not likely representative of the general population of the British Isles, but rather attract people with a lower average height.

3.5. Relationship of height and grain prices

It is interesting to gauge to what extent heights react to agricultural conditions, who will in turn affect the prices of food. Komlos (2003) used the grain prices as a proxy for agricultural conditions. We follow this strategy and investigated whether European heights reacted to agricultural conditions. As indicators of agricultural conditions, we used grain prices[72]. The purpose of this section is to complement Baten's (2000) work on height and real wages.

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[71] We read off the value from: (p.26, figure 5, "dummies".) so they should be considered approximations. Note that Scotsmen are even taller in 1740 in same figure.

[72] We are indebted to John Komlos for making us aware of the IISG database where we obtained the price data. We combined grain prices by Robert C. Allen (downloaded from: http://www.iisg.nl/hpw/allen.rar)

Van Zanden (1999) argued that around half of the income of a European worker was spent on bread made out of rye or wheat. Rye was the primary grain in Eastern and Central Europe, while it was wheat for Southern Europe and England (Van Zanden 1999). For this reason, we primarily used wheat prices[73] in the subsequent calculations. Our approach with respect to regressions for Swiss and Irish heights demand special attention: We considered using a series of rye prices in Basle for Switzerland, but values for the years 1683 to 1750 were missing, so this series[74] was not suitable for our purposes. Since most of the Swiss recruits in the dataset were born in the north western part of Switzerland, we experimented with two alternative series of grain prices in Strasbourg[75] as substitutes for Swiss prices. Rye and wheat prices were available, and we obtained better results using the rye price series from Strasbourg. To the best of our knowledge, no data for grain prices is available for Ireland, so we used the same price series as for England.

We pursued a two-fold strategy to shed a light on the influences of wheat prices on the nutritional status: Where predicted heights from spline regressions were available, we regressed those predictions on prices. Second, for all countries where we estimated trends in stature, we also added prices or wages as supplements directly to the truncated regressions that were estimated to produce the trends in figures 9 to 14.

We first explored the relationship of heights and grain prices by using predicted heights as the dependent variable. Since the spline estimates for Scotland were straight lines, we

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last access:14.06.2017) and the grain prices from the Allen-Unger Global Commodity Prices Dataset (downloaded from http://webstore.iisg.nl/hpw/allen-unger-commodities/Rye/ last access: 14.06.2017 and http://webstore.iisg.nl/hpw/allen-unger-commodities/Wheat/ last access: 14.06.2017). We used the grain prices normalized to silver per present day units. The creators of the data we downloaded carried out all of the aforementioned calculations.

[73] We used the following wheat prices: France: Paris (Although a national average was available by Robert C. Allen, we did not use this series since it began in the 1720s.). Italy: Pisa (Values for the years 1671, 1672 and 1693 were missing. We assigned the values in1670, 1673 and 1692 to the corresponding missing observations. Allen's data contained a series for Northern Italy, but it began earliest in 1700.). England: London and Southern England. Scotland: Edinburgh. The series for Paris and London and Southern England were based on Robert C. Allen's calculations. All other series were obtained from the Allen-Unger Global Commodity Prices dataset. When multiple series of prices were available for a specific country, we used the series that we considered to be most complete. We observed that series of wheat prices in specific cities within France were positively correlated. An exception was the series of wheat prices in Marseille. It was slightly negatively correlated to the series of wheat prices in Paris, as well as to the series of prices in Béziers. However, both correlations were insignificant.

[74] We also considered the series of "Kernenpreise" in Luzern by Haas-Zumbühl (1903b), but we did not obtain consistent result using this series: When using predicted heights as the dependent variable, we found a positive, significant and very large effect of "Kernenpreise" on stature. When we add these prices directly to the regressions that were executed to estimate trends in stature in Switzerland, we found a small, positive but insignificant effect of the prices on height. This may be the result of the unspecified nature of "Kernenpreise", that is, we do not know to which grain they refer.

[75] Those prices were again Robert C. Allen's calculations.

did not study Scottish heights, and since the spline regressions were unreliable for Ireland, this country was also excluded. As explanatory variables, we considered the prices in the year of birth and the average prices for the first 16 years of a recruit's life[76]. We employed a similar strategy in chapter 2 where we studied heights in the Holy Roman Empire.

To assess the strength of the estimated effects, we calculated the effects of a one standard deviation change in the grain prices, respectively the effects of a one standard deviation change in the average grain price for the first 16 years of the life of an individual. Those effects were easier to interpret that the coefficients[77] in regressions where the explanatory variable was not standardized. Because we observed only few (N=69) English recruits born after 1735, we also estimated regressions where predicted heights for years of birth after 1735 were excluded.

We found a negative influence of wheat prices on stature in all countries studied, but the standardized effects varied between countries (table 2). The French were most susceptible (in terms of the effect of 16-year averages) to agricultural fluctuations, followed by the Swiss and the Italians. Englishmen seem to have been most insulated from fluctuations in agricultural prices, but effects were within the range of those for Italians when only years of birth until 1735 were taken into account (table 2). The effect of the 16-year averages was always larger in absolute terms compared to the effect of prices at birth, as could be expected since the nutritional status is a cumulative measure. Contrary to effects of prices at birth, the average prices were always significant.

The variation in stature explained by the grain prices varied substantially: The 16-year averages generally explained more variation in height than did the prices at birth, but the difference was only substantial for French heights and in the regression of English heights restricted to years of birth before 1735. In all other specifications, only a small fraction of the total variation in predicted heights was explained by the grain prices.

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[76] We are convinced that this specification captures the years of growth of an adolescent where most of physical growth occurs. In particular, by using 16 years, we ensure that the adolescent growth spurt is completely included.

[77] The coefficient estimates are available upon request.

Table 2: Height and grain prices: Regression results.

Dependent variable: Country-specific predicted height in cm based on constrained spline regressions				
Country	Grain price at birth	Average grain price during the first 16 years of life	N	Adjusted-R^2
France	-0.6***		103	0.1
		-1.8***		0.7
Italy	-0.1		98	0.0
		-0.4**		0.0
England	-0.1**		94	0.0
		-0.3***		0.1
Switzerland	-0.2		91	0.0
		-0.9***		0.2
England until 1735	-0.1		74	0.0
		-0.5***		0.4

Sources: See the text. *Notes:* *: $p<0.1$, **: $p<0.05$, ***: $p<0.01$. Effects were standardized to a one standard deviation change in prices based on samples used in the respective regressions. Results were rounded to one decimal place. The dependent variables were country-specific predicted heights from constrained regressions. Robust standard errors were used. Significances were identical when standard errors were bootstrapped (1000 replications). The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. All models included a constant (value not shown).

Subsequently, we added the grain price data to the truncated regressions[78] that we used to estimate the trends in stature we discussed in the preceding section. We only depict the results based on constrained regressions in table 3, since the results from unconstrained regressions were qualitatively identical. The magnitudes of the effect were again standardized to a one standard deviation change in the standard deviation of respective explanatory variable.

Results were not as clear-cut as in the aforementioned regressions: Except for Ireland, prices at birth were never significant, and the direction of the estimated effects as not always negative (table 3). We estimated a positive, but insignificant effect of prices at birth on height in Switzerland and France, as well as a positive and insignificant effect of 16-year average prices in England[79]. For Scotland and Ireland that we did not study in the previous sections, we found negative effect of grain prices, but only prices at birth in Ireland were significant (table 3). For continental Europe, the estimated effects of grain prices at birth were all extremely small, but effects of average prices were of a reasonable

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[78] All models contained controls for ages under 24, controls for special troops, controls for decades of birth and dummy for enlistment during times of war. Where applicable, the regressions also contained controls for regions.

[79] This result for England was robust the exclusion of years of birth after 1735 or 1710. If years of birth after 1720 were excluded, the effect of 16-year averages became negative, but was extremely small and insignificant.

magnitude, but they were not significant for Switzerland[80] and France. Compared to the results in table 2, Italians were now more vulnerable to variations in the average grain than were the Swiss or the French. Prices in the year of birth had a larger and negative magnitude for the British Isles compared to continental Europe, but were only significant for Ireland. Effects of average prices were smaller in absolute terms compared to continental Europe, and even positive for England. But none of these effects was significant.

Table 3: Height and grain prices: Constrained truncated regression results

Dependent variable: Height in cm Country	Grain price at birth	Average grain price during the first 16 years of life	N
France	0.1	-0.8	47,117
Italy	-0.1	-0.9**	8,485
Ireland	-0.3*	-0.2	6,060
Switzerland	0.1	-0.5	2,658
England	-0.2	0.4	1,356
Scotland	-0.1	-0.3	1,493

Sources: See the text and table 2. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Effects were standardized to one standard deviation of prices based on samples used in the respective regressions. France: Cluster-robust standard errors were used. All other regressions: Robust standard errors were used. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. Sigma was constrained to 2.534 Fi (6.86 cm).

Our results support the conclusion that the nutritional status of European population was dependent on harvest conditions, at least on the continent. However, the nutritional status of an individual is influenced by a vast number of additional factors (see e.g. Steckel 1995), so a mono-causal explanation of our findings is too short-sighted. Data on other determinants of height (e.g. the disease environment, workload, market integration, inequality) is generally scarce for the time period we study.

We would like to point to a second prominent factor that may also contribute to explanation of the decline in stature in the second half of the 18th century: The relative price of protein. Komlos (1998) listed the substitution of protein for carbohydrates as a

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[80] We hypothesize that the effect could have been noisily estimated due to our use of rye prices in Strasbourg.

contributing factor to the decline in stature during the industrial revolution, and Stolz et al. (2013) discuss the relative prices of meat and grain in the interpretation of their findings. Our subsequent discussion is necessarily qualitative, because data on meat prices is either completely unavailable, too fragmented or did not exhibit sufficient variation to be included in regressions.

Stolz et al. (2013) calculated relative prices of meat and grain in Europe, but the sources of their series did not match the countries we study[81]. The price movement was similar in all regions: A long-term decline in the relative price of meat in the 18th century, and a subsequent increase in the price in the 19th century. The magnitude of the declines was different across the regions studied. However, the authors expressed a preference to use the price of milk, but they argued that it is unavailable (Stolz et al. 2013, footnote 68). We were able to find decadal averages of prices of milk[82] and beef[83] pertaining to Luzern in Switzerland (Haas-Zumbühl 1903a, 1903c), as well as milk and beef prices in London in the Allen-Unger Commodity database. We calculated the relative prices of protein and grain by dividing the prices of meat respectively the price of milk by grain prices (Switzerland: Haas-Zumbühl 1903b; England: Previously used wheat prices in London by Robert C. Allen). To the best of our knowledge, consistent series of meat or milk prices are unavailable for the other countries studied.

We could not detect an unambiguous long-term trend in the relative price of protein in Luzern (figure 15), but some features of the price movements deserved further attention and suggested that the relative prices we calculate were reliable: Two hikes in the prices of meat correspond to events that reduced the stock of animals that were mentioned by Haas-Zumbühl (1903c, p.376): An epizootic[84] in 1682 and death[85] of livestock in 1732. Interestingly, the former did not manifest itself in a substantial increase in the relative price of milk, but the latter did. In general, both price series exhibited a stronger co-movement before the 1750s than afterwards. Relative milk prices then increased

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[81] The authors determined relative prices for four European regions: Central-West, East, South and Portugal. The series for Central Europe was based on prices in Amsterdam, and Southern Europe was solely based on prices in Barcelona for the entire 18th century. See annotations in: (Stolz et al. 2013, p.566, figure 8) for a detailed description and the sources of East-European prices.

[82] It should be noted that the prices did not vary necessarily between subsequent decades: Haas-Zumbühl (1903a).

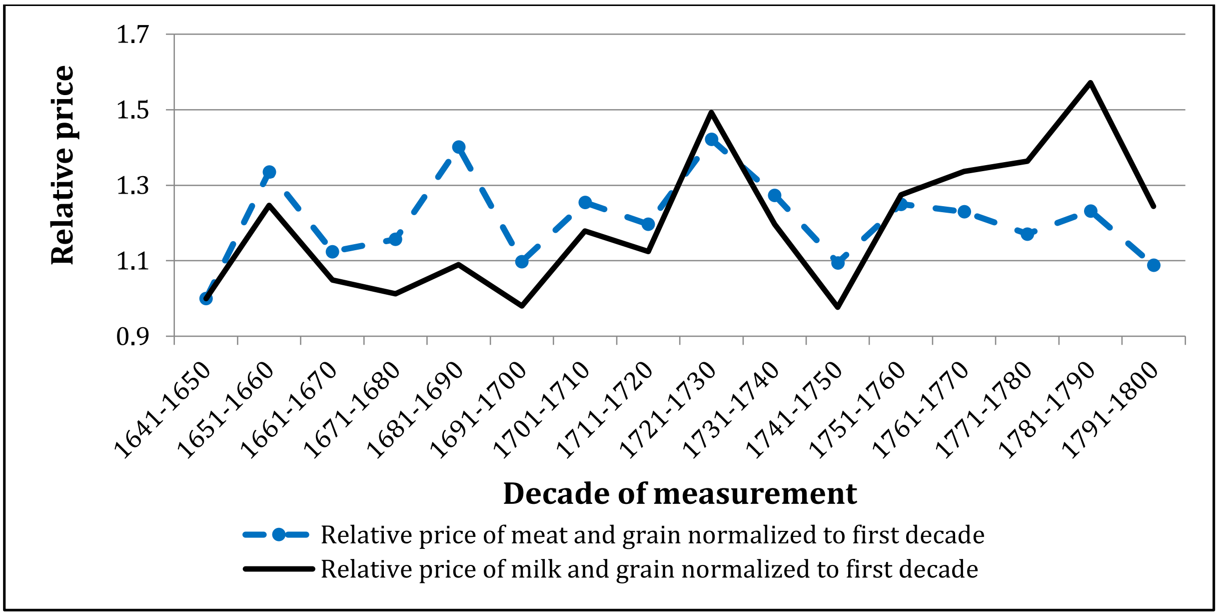
[83] Prices are for oxen and veal. Both series were highly correlated (0.97, significant at 1%). Thus, we only used the series of oxen prices.

[84] "Viehseuche".

[85] "Viehsterbent" [sic].

dramatically, while the relative price of meat remained largely constant until the decade of the 1790s, when the relative milk price also exhibited a sharp decline (figure 15). A strong increase in the relative price of protein in the 1720s corresponded well to a local minimum in Swiss heights (figure 11). What's more, the decline in stature in the 1750s and 1760s corresponded to a period of continually increasing relative prices of milk. Thus, at least for Switzerland, variations in the relative price of protein may have contributed to the variation in stature.

Figure 15: Relative prices of protein and grain in Luzern



Sources: See the text and (Haas-Zumbühl 1903a, 1903b, 1903c). *Notes:* Relative prices were calculated as the ratio of decadal average prices of milk respectively oxen meat divided by decadal average prices of grain. Yearly figures for meat and milk prices were not available in the sources used. All relative prices are our calculations.

Milk, beef and grain prices in England were available on a yearly basis with small gaps. Because the yearly fluctuation was quite pronounced in all price series, we studied decadal averages of relative prices. There appears to be no co-movement of relative milk and meat prices in London (figure 16). The relative price of meat increased in the 18th century compared to the 17th century, and except for the 1740s, the relative price remained largely constant throughout the 18th century. Furthermore, the lowest relative price of milk in the 18th century was attained in the 1740s. This may have partly offset the increase in the relative price of meat and kept protein supply on an acceptable level[86].

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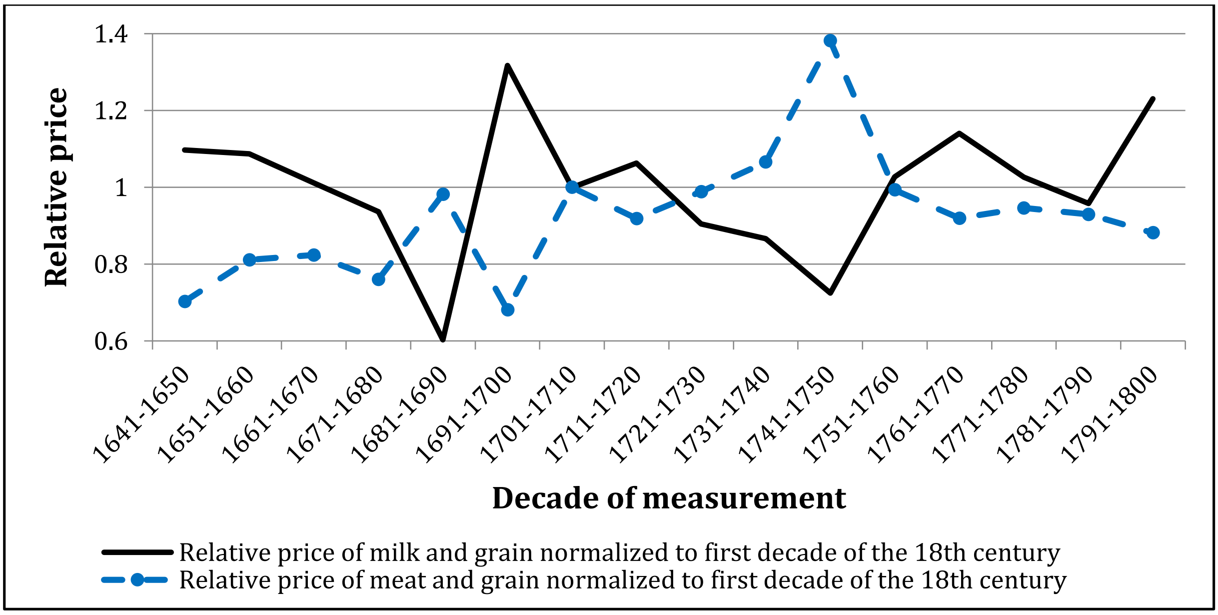
[86] A similar pattern was evident in the decades 1681-1690 and 1691-1700, but in the latter case with hikes in relative milk prices and lower relative meat prices.

The much lower amplitude of fluctuations in relative prices, compared to the movements in relative prices in Switzerland, and decades with fairly stable relative meat prices, suggests that the relative price of protein can contribute little to the explanation of our English height estimates.

Figure 16: Relative prices of protein and grain in London



Sources: See the text, Allen-Unger commodity database and Robert C. Allen. *Notes:* Relative prices were calculated as the ratio of decadal average prices of milk respectively beef divided by decadal average prices of wheat. All relative prices are our calculations.

Although we have presented evidence that 17th and 18th century heights were dependent on harvest conditions, this tentative study of effects of protein prices should alert the reader that we do not attempt a mono-causal interpretation but rather provide building blocks that foster the understanding 18th century European height trends.

For example, Komlos (1998) provided further possible explanations for the decline in stature in most European countries in the 2nd half of the 18th century: Per capita food consumption declined in Europe in the second half of the 18th century (Komlos 1998). Bread prices increased due to population growth, and arable land could not expand rapidly enough (Komlos 1998). The price of food (relative to clothing) increased in the second half of the 18th century (Komlos 1998).

3.6. Conclusion

We analyzed the nutritional status of the population in 10 European countries. Due to the respective sample sizes, we were only able to estimate trends for 6 countries. Corse people were by far the shortest, and Swiss and Italian recruits were tallest. The nutritional status improved for French recruits from the 17th century to approximately 1715. In Switzerland as well as France, a decline in stature can be detected in the 1720s Afterwards, the nutritional status improved considerably, resulting in peak heights, attained in the middle of the century. Subsequently, heights declined again in France and Switzerland. Our estimates of French heights were consistent with Komlos '(2003) pioneering estimates of 17th and 18th century French heights. Our estimates of Swiss heights constitute the first of their kind.

Italian heights followed a long-term upward trend, interrupted by cyclical periods of decline. Heights did not decline in the second half of the 18th century, but stagnated. This is a new result for Italy and it stands in contrast to A'Hearn's (2003) results of declining heights.

Irish heights followed a cyclical pattern of similarly strong upswings and downswings, and were consistent with the existing evidence. English and Scottish heights stagnated. In particular, for Scotland, this could have been the result of a low sample size that did not allow us to reject the null hypothesis that no trend in heights existed. Our estimates of English and Scottish heights were not well matched to most of the established estimates of these heights in the literature. We proposed sample selection is a contributing factor for this finding.

We demonstrated that variations in grain prices as indicators of harvest conditions can contribute to the explanation of our estimated trends, in particular for continental Europe. Results pertaining to the British Isles were on a less solid basis. The magnitudes of the estimated effects of grain price variations were not constant across countries. The French, Swiss and Italians were vulnerable to fluctuations in grain prices, and recruits from the British Isles were less vulnerable.

The trajectory of Swiss heights is consistent with the development of the relative price of protein, calculated as the relative prices of milk and oxen to grain. For English heights, we could not obtain a similar result. Our results add new evidence to the existing literature that the nutritional status of pre-industrial continental European populations was not yet freed from the shackles of agricultural fluctuations and food scarcities. We cannot draw a similar conclusion for the British Isles, because of contributing two factors: Firstly, the very likely sample-selection issue and secondly the inadequacy of the supplementary data. With future improvements in the availability of price data, research could be directed towards more elaborate models of the interaction of prices, harvest conditions and the nutritional status.

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4. Notes on A'Hearn's restricted truncated estimator

4.1. Introduction

In 2004 A'Hearn established that it is possible to improve the performance of the truncated normal regression (TNR) by estimating a model where the standard deviation is set to a fixed value before estimation. If the fixed value is reasonably close to the value of the standard deviation in the population, this "restricted" estimator is more precise than the conventional TNR and has a reasonably small bias.

With this paper, we complement A'Hearn's (2004) work in several aspects: We first re-estimate his constant-only model. We assess the relative performance of the restricted and the unrestricted TNR using Wallace's (1972) weak MSE criterion, which is slightly different compared to the criterion than A'Hearn (2004) used. Furthermore, we supplement A'Hearn's (2004) work by explicitly calculating the boundaries where the restricted estimator performs better than the unrestricted one. In addition, we discuss the direction of the bias possibly introduced by restricting the standard deviation. We also estimate a restricted linear model with a single explanatory variable and compare its performance to an unrestricted one. Again, we also discuss the direction of the bias found in our simulations. Furthermore, we study which parameter estimate is the source for the superiority of the restricted estimator. This paper is organized as follows: Section 2 provides an introduction to the estimator studied in this paper, section 3 describes the method we use to analyze our simulation results. The results are contained in section 4. Section 5 concludes.

4.2. ML estimation, restricted and unrestricted

Human heights follow a normal distribution (Tanner and Eveleth 1990, p.4). Yet, when analyzing historical height data, researchers are often confronted with a missing data problem, in particular if the data are obtained from military records.[1] Missing data in military records are those observations with heights below a certain minimum height requirement. As a consequence, the height distribution in the sample is truncated normal and hence the distribution is not identical to the height distribution of the population. All observations below a certain threshold are not observed. We follow A'Hearn's (2004)

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[1] See, for example (Koch 2012) or (Zehetmayer 2011)

terminology and denote this threshold (the point of truncation) τ, or “tau”. The problem of truncation can be motivated in the latent variable framework (see for example Cameron and Trivedi 2005, p.532). Consider the population relationship

$$y^* = \alpha + x\beta + u$$

where α is a constant, β is a vector of slope parameters and u is the error term. We do not observe the latent variable y^* but rather y which is observed according to the selection rule

$$y = \begin{cases} -, if\ y^* \leq \tau \\ y^*, if\ y^* > \tau \end{cases}$$

where "– " denotes a missing observation and τ is the point of truncation. Note that not only the value of the dependent variable is unobserved below the point of truncation, but the corresponding values of the explanatory variables are also not observed. So, if y is below the point of truncation, we are missing the complete observation (y^*, x) i.e. we do *not* observe $(-, x)$.

If the parameters in the population are estimated by OLS applied to the truncated data, the OLS estimates are inconsistent (Cameron and Trivedi 2005, p.530). Fortunately, consistent estimators for truncated data are available.[2] The most common estimator that is used in anthropometrics is the truncated normal maximum likelihood regression (TNR) estimator (Tobin 1958). The TNR makes a distributional assumption about the dependent variable, respectively the error term. It is assumed that $u \sim N(0, \sigma)$. σ or “sigma” is the standard deviation of the error term[3]. Intuitively,[4] the estimator uses the facts that the distribution of the data as well as the point of truncation τ are both known. With this information the density of the truncated data can be written down analytically and a maximum likelihood estimator based on this truncated density can be constructed.[5] The log-likelihood (based on Cameron and Trivedi 2005, p.538, own modifications) for the population model described above is:

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[2] Apart from the ML estimator discussed below there exist other estimators relying on different assumptions compared to the truncated regression. For example, an estimator that relaxes the normality assumption is the Symmetrically Trimmed Least Squares Estimator (Powell, 1986).

[3] Sigma corresponds to the standard deviation of the dependent variable if *x* is not random.

[4] You are referred to (Cameron and Trivedi 2005) for a detailed technical discussion of the estimator.

[5] We focus on data that is truncated from below. The estimator can also be used if the data is truncated from above or if the data is truncated from both sides. However, the log-likelihood has to be slightly modified in these cases.

$$ln\, L(\alpha,\beta,\sigma) = \sum_{i=1}^{N}\left\{-\frac{1}{2}\ln\sigma^2 - \frac{1}{2}ln2\pi - \frac{1}{2\sigma^2}(y_i-\alpha-x_i\beta)^2 - \ln(1-\Phi\left(\frac{\tau-\alpha-x_i\beta}{\sigma}\right))\right\}$$

where N is the number of observations, σ^2 is the variance of the error term and Φ is the standard normal distribution function. The TNR estimator computes estimates $(\hat{\alpha},\hat{\beta},\hat{\sigma})$ that maximize the expression above.

A'Hearn (2004) suggested maximizing a similar likelihood. He replaced the parameter σ, the estimated standard deviation of the error term, with a standard deviation of heights found in modern populations, which is 6.86 cm. Therefore, the log-likelihood maximized in his approach is

$$lnL_R(\alpha,\beta) = \sum_{i=1}^{N}\left\{-\frac{1}{2}\ln 6.86^2 - \frac{1}{2}ln2\pi - \frac{1}{2*6.86^2}(y_i-\alpha-x_i\beta)^2 - \ln(1-\Phi\left(\frac{\tau-\alpha-x_i\beta}{6.86}\right))\right\}$$

which is now maximized over the choice of (α,β) only, since σ has been set to a fixed value. A'Hearn (2004) calls this a "restricted maximum likelihood estimator". In applied work, it is also known as the "constrained"[6] truncated regression estimator.

4.3. Our methodology and its relation to A'Hearn's results

A'Hearn (2004) performed a Monte-Carlo-simulation study to assess the relative performance of the restricted and unrestricted versions of the TNR. His population model for the data was

$$y^* = \alpha + u$$

where α is a constant, $u \sim N(0,\sigma)$ and the data was truncated according to the selection rule described in the previous section. A'Hearn (2004) used a value for α of 165.[7] He carried out simulations for several sets of parameters: σ ranged from 6 to 8 in steps of 0.5 and including 6.86, τ ranged from 159 to 167 in steps of 2 and the sample sizes varied between 250, 500 and 1000 observations. A' Hearn (2004) was able to show that for a given truncation point, there exists an interval for σ where the restricted estimator performed superior compared to the unrestricted TNR. He validated the use of the restricted estimator using a bias and variance trade-off. His simulation results indicated that the restricted TNR estimates have a smaller variance compared to the unrestricted

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[6] Note that this term can be misleading since we are not maximizing the log-likelihood subject to an inequality constraint but subject to an equality constraint.

[7] A'Hearn (2004) used this particular value *"For the sake of direct applicability to practical research situations [...]"* (A'Hearn 2004 p.14)

estimates. On the other hand, if the imposed restriction is not correct, the restricted estimates will be biased.

The criterion A'Hearn chose to compare the TNR and the restricted TNR (RTNR) was the mean square error (MSE). The MSE for a scalar estimator $\hat{\theta}$ is defined as (Greene 2003, p.887):

$$MSE(\hat{\theta}|\theta) = Var(\hat{\theta}) + \left(BIAS(\hat{\theta}|\theta)\right)^2$$

where θ denotes the population parameter to be estimated. A'Hearn (2004) calculates the MSE of $\hat{\alpha}$ for the restricted and the unrestricted estimator. Where the difference between the MSE of the unrestricted and the MSE of the restricted estimator was positive, the restricted estimator was superior.

Since we extend A'Hearn's (2004) work to a model that contains a single explanatory variable, the MSE definition above is not applicable: If one estimates not a single parameter, but a $K \times 1$ vector[8] of parameters $\widehat{\boldsymbol{\theta}}$, the mean square error is defined as (Greene 2003 p.887)

$$MSE(\widehat{\boldsymbol{\theta}}|\boldsymbol{\theta}) = Var(\widehat{\boldsymbol{\theta}}) + BIAS(\widehat{\boldsymbol{\theta}}|\boldsymbol{\theta})BIAS(\widehat{\boldsymbol{\theta}}|\boldsymbol{\theta})'$$

where now $Var(\widehat{\boldsymbol{\theta}})$ is the $K \times K$ covariance matrix of the estimates and $BIAS(\widehat{\boldsymbol{\theta}})$ is a $K \times 1$ vector. When estimating a vector of parameters, the resulting $MSE(\widehat{\boldsymbol{\theta}}|\boldsymbol{\theta})$ is thus a *"mean square error matrix"* (Goldberger 1991, p.256). The fact that the mean square error is not a scalar, as is the case when estimating a single parameter, makes the comparison of different estimators based on the difference in MSE more difficult. Toro-Vizcarrondo and Wallace (1968) suggest comparing the performance of a restricted linear OLS regression to the unrestricted linear regression by assessing whether the difference in the MSE matrices of the unrestricted and the restricted estimator is a positive definite matrix. If this is the case, the restricted estimator will be superior compared to the unrestricted one (Toro-Vizcarrondo and Wallace 1968, p.560). This criterion demands *"[...] the mean square error for each non-zero linear combination of [the restricted estimator] to be not*

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[8] K denotes the number of parameters to be estimated.

greater than the MSE for the same linear combination of [the unrestricted estimator]”[9] (Toro-Vizcarrondo and Wallace 1968, p.560).

Wallace (1972) noted that this criterion is very strict and consequently he proposed a weaker criterion based on the MSE matrix[10]. Wallace (1972, p.691) suggests to use the trace[11] of the MSE matrix as criterion.

$$tr\left(MSE(\hat{\boldsymbol{\theta}})\right) = \sum_{i} MSE(\hat{\theta}_i)$$

(see Wallace 1972, p.691, equation 8), which is the sum of the individual mean square errors of all parameters in the model.

Wallace (1972, p.691) notes that the trace of the MSE matrix *“[...] is the "average" squared Euclidian distance of the point $\hat{\theta}$ from θ, whatever the dimension of the parameter space.”*

This criterion is also known as “Wallace’s weak MSE criterion”.

The restricted estimator will be superior to the unrestricted estimator if the trace of the MSE matrix of the restricted estimator is smaller than the trace of the MSE matrix of the unrestricted estimator. We use this criterion to assess the performance of the estimators we study.

Our approach differs in one additional aspect from A’Hearn’s (2004) work: We chose to include the MSEs of $\hat{\sigma}$ (the estimate of the standard deviation of u) in the MSE sums as well: The *restricted* sigma can be interpreted as an estimate that does not have a variance but if the restriction is incorrect, it does have a bias. In case of the unrestricted estimator, σ is estimated consistently. Therefore, in this case $\hat{\sigma}$ has no bias but it has a variance. While the MSE of $\hat{\sigma}$ in the restricted case can be calculated as $(\sigma - 6.86)^2$ (where σ is the standard deviation of u used to create the data), the variance of the estimate $\hat{\sigma}$ in the unrestricted case cannot be calculated analytically. Consequently, we do not know how the difference in MSEs between the restricted and the unrestricted estimator of σ behaves if we do not simulate it. The parameter σ is interesting itself, so its MSE is interesting, too. As a result, we interpret A’Hearn’s (2004) constant only model as a regression in which

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[9] The designations “restricted estimator” and “unrestricted estimator” were substituted in by the authors of the paper at hand. In (Toro-Vizcarrondo and Wallace 1968, p.560) the restricted and unrestricted estimators are represented by Greek letters.

[10] Again in the context of a linear model.

[11] The trace of the MSE matrix is the sum of the diagonal elements of the MSE matrix.

two parameters are estimated: The constant as well as sigma. This approach also has the advantage of allowing us to assess which parameter estimate is most influential for the relative performance of the restricted and unrestricted estimator. The same is true for the model that contains an explanatory variable. In this case, each MSE sum (for the restricted as well as the unrestricted estimator) is:

$$MSE = MSE(\hat{\alpha}) + MSE\left(\hat{\beta}\right) + MSE(\hat{\sigma})$$

From now on, when we speak of MSE, we always refer to the trace of the respective MSE matrix, the sum of **all** MSEs of the parameters in the model.

4.4. MSE performance: Simulation results

We use the same range of values for σ and τ as A'Hearn (2004), but we use a finer grid of steps in σ and τ. σ ranges from 6 to 8 in steps of 0.1, and including 6.86. τ ranges from 159 to 167 in steps of 1. We hope that this provides more detailed insights into the shape of the region where A'Hearn's (2004) estimator is superior. Each MSE is calculated from 2000 replications[12] for each combination of σ, τ and N. In a case where the estimator failed to converge for a particular set of random variables, these observations were dropped and another replication using new random values was performed. For each new combination of parameters σ, τ and N, the same starting value of the random number generator was used.[13] The simulation results consist of 198 data points for each number of observations N=250, N=500 and N=1000. Each data point is a triplet, consisting of a particular value for σ, τ and the difference in MSE between the unconstrained and the constrained estimator (ΔMSE). The set of all the triplets $(\sigma, \tau, \Delta MSE)$ can be represented as a surface in $\mathbb{R}^3$ (figure 1). This also is the way A'Hearn (2004) represented his results (A'Hearn 2004, figure 6).

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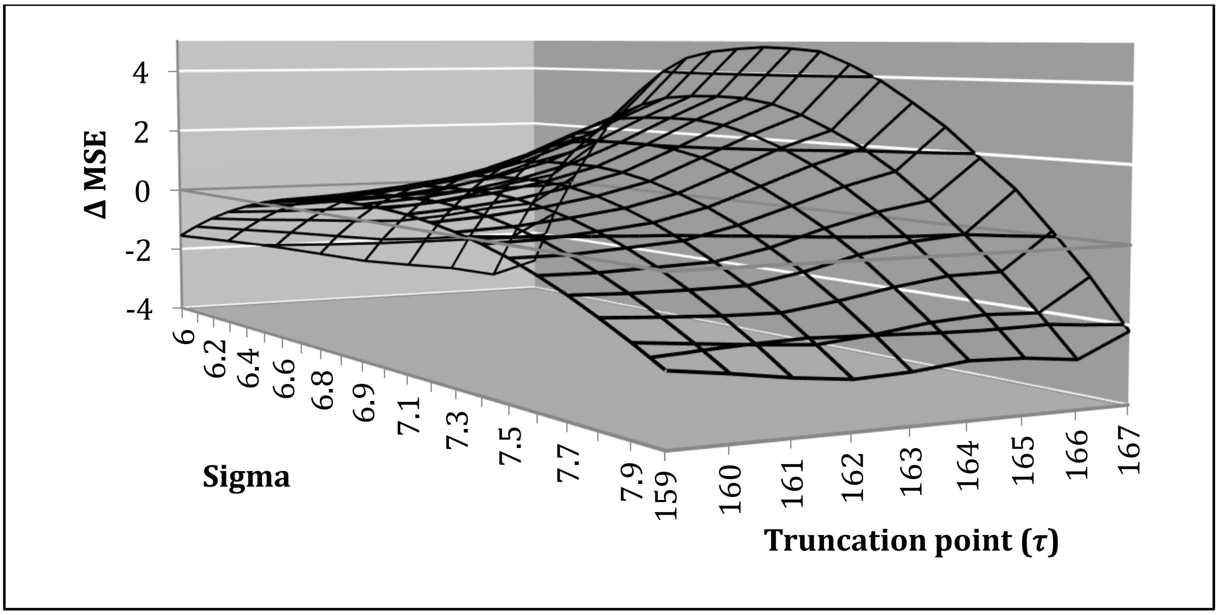
[12] A'Hearn (2004) also used 2000 replications.

[13] See references.

Figure 1: MSE simulation results



Sources: See the text. *Notes:* N=500. Simulation results for the constant only model.

Of central interest are the values for σ and τ where the restricted estimator performs better than the unrestricted one. A'Hearn (2004) outlines these values only for three combinations of $\sigma_u$and τ in a graph (A'Hearn 2004, figure 7). He arrives at the conclusion that *"[...] if the σ restriction is approximately true (within roughly 0.5 cm) and the truncation point exceeds about 160 cm (or a point about one standard deviation below the mean), the restricted estimator offers substantially better performance"* (A'Hearn 2004, p.16). This statement is essentially correct, but compared to A'Hearn (2004), we chose a different form of graphical representation that allows us to assess the influence of the sample size, and in particular the influence of the truncation point on the relative performance of the estimators in a more accessible way. The boundaries of the region where the restricted estimator is superior to the unrestricted one are those combinations of $\sigma$and τ for which $\Delta MSE = 0$. The surface depicted in figure 1 can be interpreted in the way that ΔMSE is a function of σ and τ

$$\Delta MSE = f(\sigma, \tau)$$

It remains to specify a function $f(\circ)$ with the property that for every triplet in our sample we have $\Delta MSE = f(\sigma, \tau)$, that is we need a function that interpolates the surface shown in figure 1. Such a function can be represented by a "thin plate spline" (Green and

Silverman 1994, pp.142-144). With such a "thin plate spline" function[14], we can calculate the value of ΔMSE for any given combination of σ and τ. This allows us to compute the zeros of the ΔMSE surface[15]. Since the number of zeros is uncountable (there exist infinitely many combinations of σ and τ for which the MSE-difference is zero), we use a fixed grid of points for τ (from 159 to 167 in steps of 1) and use a numerical algorithm[16] to calculate the corresponding values for σ such that the MSE-difference is zero.[17] Considering the shape of the surface in figure 1, one set of zeros of ΔMSE is below and one set of zeros of ΔMSE is above 6.86. This procedure is carried out for all three numbers of observations separately. Those boundaries are represented in the graphs that follow.

4.4.1. Re-estimation of A'Hearn's (2004) model

In this section, we compare A'Hearn's (2004) results which are based on the MSE of the constant alone with our results which are based on Wallace's (1972) weak MSE criterion. Our simulations yielded the following results: With an increase in the sample size, the region where the restricted estimator is superior concentrates more around 6.86 which is the value of the σ-restriction (figure 2). With a high truncation point, the restricted estimator is superior for a wider range of σ than for a low truncation point. This effect becomes smaller with an increase in the sample size (figure 2).

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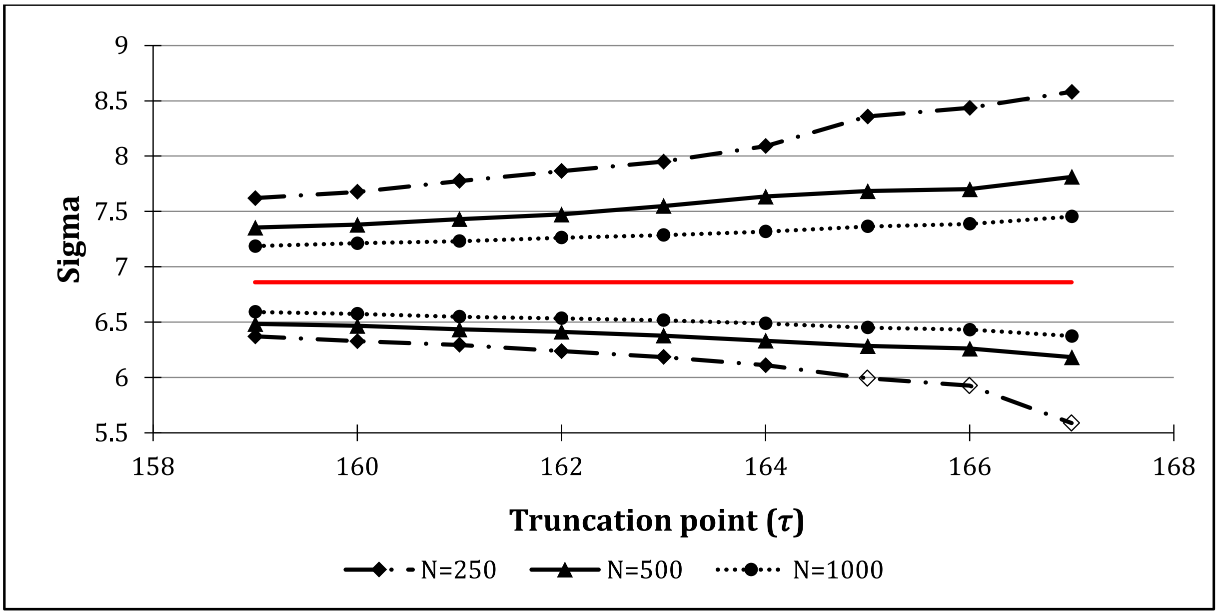
[14] A "thin plate spline" that interpolates *n* points in $\mathbb{R}^3$ depends on *n+3* parameters. For a given set of points, these parameters are unique (Green and Silverman 1994, pp.143 theorem 7.2). The advantage of the "thin plate spline" representation is that once these *n+3* parameters have been calculated, it is possible to calculate the value of the spline function (and therefore the value of the MSE difference) for *any* values of σ_u and τ (not just the values of σ_u and τ found in our simulation).

[15] Note that we are not willing to make a statement about the shape of the ΔMSE surface for values of σ_u and τ we did not use in the simulations. Consequently, we only calculate the zeros of the ΔMSE surface for values of σ_u and τ bounded by the values used in the simulations.

[16] For any given value of the grid variable τ, the function representing the ΔMSE surface has two zeros, one below and one above 6.86. Given a particular the grid value for τ, we used a one dimensional Newton-Raphson procedure to calculate the zeros: We chose a starting point for the procedure below 6.86, and after the algorithm had converged, a starting point above 6.86.

[17] For some parameter combinations, the zeros of the ΔMSE were not located inside the interval [6;8]. Sometimes, in particular if the sample size was low and the truncation point was high, the upper bound of the region of superiority was above 8. In this case, we extended the range of σ_u to be sure we included a zero in our data. The same principle was applied if a zero-crossing was expected below 6. Where this was the case is indicated in the corresponding figures.

Figure 2: Boundaries of superiority of the RTNR

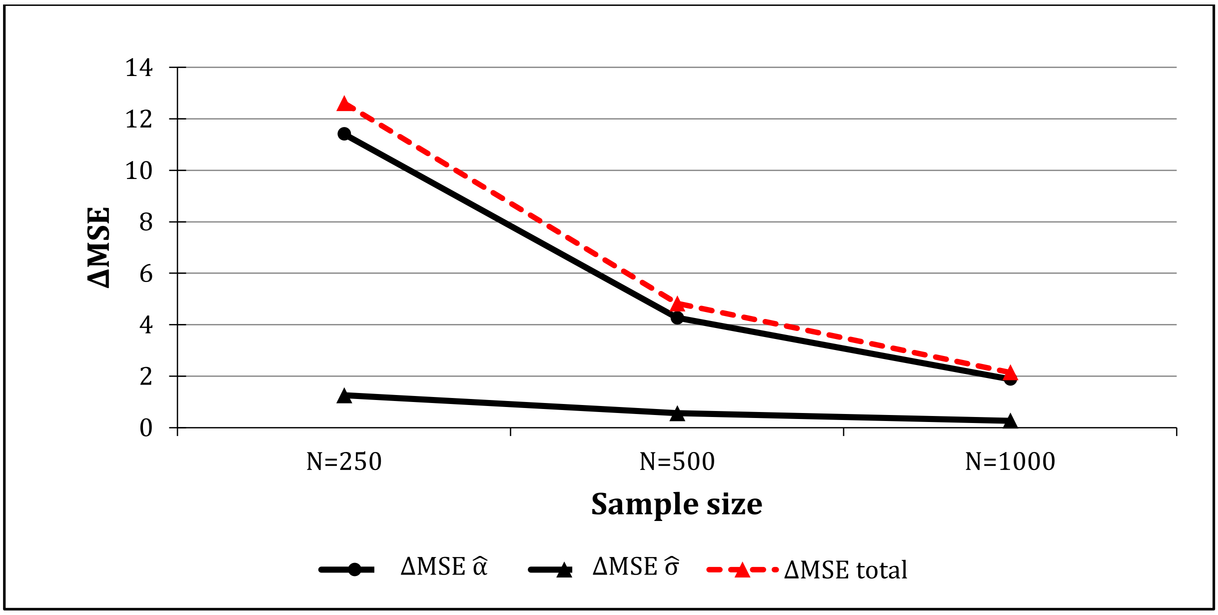


Sources: See the text. *Notes:* For N=250, we used σ values ranging from 6 to 8.6. The MSE difference was still positive for N=250, sigma=6 and $\tau = 165, 166$ *or* 167. Thus, the corresponding crossings are entirely based on the behavior of the spline function and should be considered approximate (represented by not filled diamonds in the figure). Red line: $\sigma = 6.86$ Lines above the solid red line are upper bounds. Lines below the solid red line are lower bounds. All combinations of σ and τ that are below the upper bound and above the lower bound are those combinations of $\sigma$and τ where the restricted estimator is superior to the unrestricted one.

Next, we study the magnitude of the differences in MSE between the restricted and the unrestricted model. We focus on positive differences in MSE, that is to say we examine "how much better" the restricted estimator is in some cases. Furthermore, we investigate which parameter estimate contributes most to the positive difference in MSE. We do this by looking at the individual MSE differences for each parameter estimate. To take a conservative position towards the relative performance, we only consider the largest differences in MSE for the whole range of σ and τ.

Our simulations show that a large part of ΔMSE can be attributed to the estimate of the constant, while the contribution of the σ estimate is very small (figure 3). For a sample size of 250 observations, the total difference in MSE is around 12.5. $\Delta MSE(\hat{\alpha})$ contributes around 11.4 to it and $\Delta MSE(\hat{\sigma})$ contributes only 1.1. Consequently, the superiority of the restricted estimator can for the most part be attributed to a better estimation of the constant. For the constant as well as $\hat{\sigma}$, the difference in performance becomes smaller as the sample size increases (figure 3).

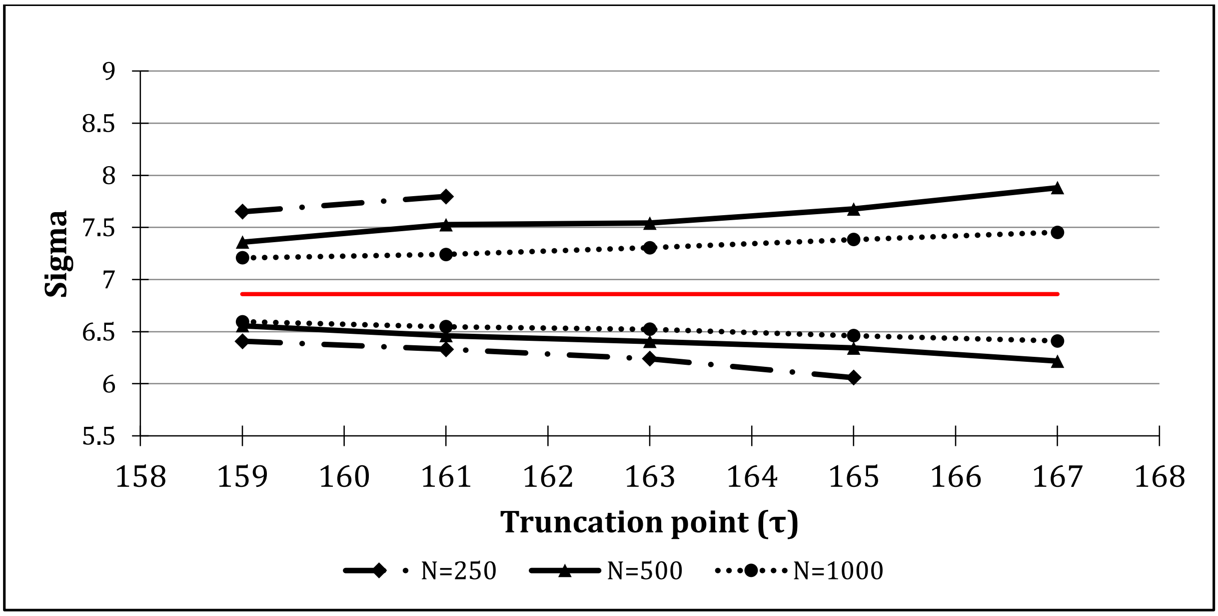
Figure 3: Maximum of ΔMSE



Sources: See the text. *Notes:* ΔMSE refers to the difference in MSE of the unconstrained minus the MSE of the restricted model. The maximum is calculated on the basis of all values of σ and τ for the respective samples sizes.

Furthermore, we calculated the boundaries where the restricted estimator is superior using A'Hearn's (2004) data (figure 4). Note that in A'Hearn's (2004) original work, the difference in MSE between the unconstrained and the constrained TNR was still positive for sigma=6 respectively sigma=8 if the sample size was N=250 (see A'Hearn 2004, p.15, table3). Those parameter combinations were not depicted in figure 4.

Figure 4: Boundaries of the RTNR, A'Hearn's data



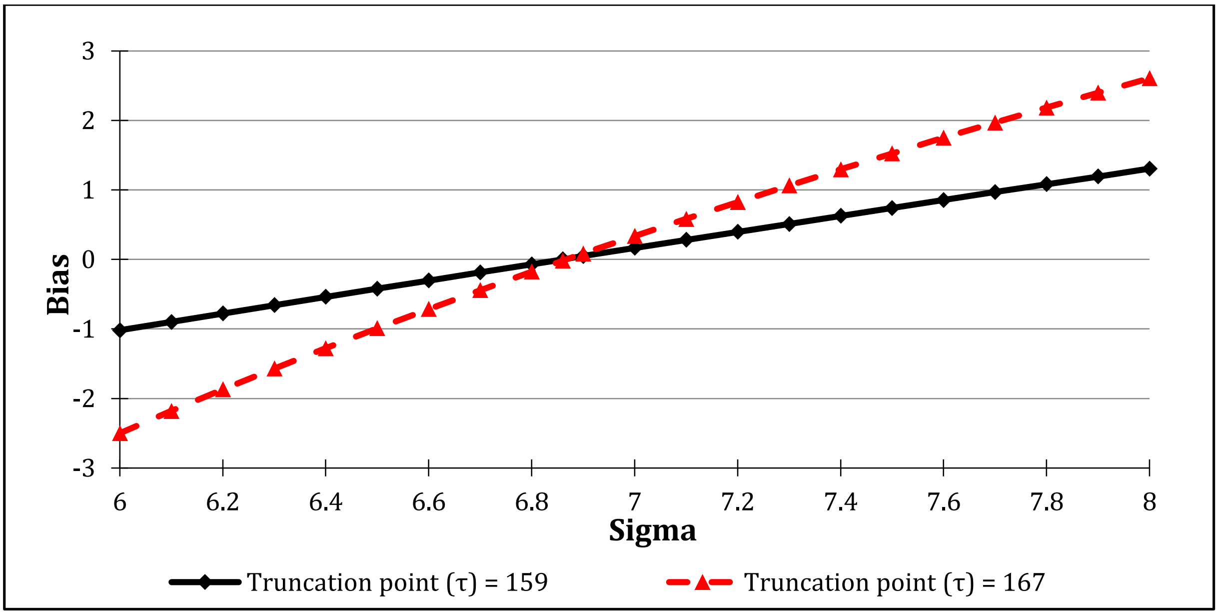
Sources: See the text. *Notes:* Red line: $\sigma = 6.86$ Lines above the solid red line are upper bounds. Lines below the solid red line are lower bounds. All combinations of σ and τ that are below the upper bound and above the lower bound are those combinations of σ and τ where the restricted estimator is superior to the unrestricted one. Source: values taken from A'Hearn (2004, p. 15, table 3).

Where there are differences between figures (2) and (4) they are minimal, given that a comparison is possible. This result is a consequence of the fact that ΔMSE is dominated by the effect of estimating the constant. Taken together, our results indicate that A'Hearn's (2004) strategy to use the scalar MSE criterion did not misrepresent the relative performance of the estimators. Consequently, we can agree with A'Hearn's (2004, p.16) claim that *"At truncation points well above the mean in small samples, the restricted estimator offers dramatically better precision, far outweighing its bias. In contrast, at truncation points well below the mean in large samples, unconstrained estimation is generally preferred; it performs less well only in the immediate neighborhood of σ = 6.86 cm, and then only slightly."*

We now discuss an issue that is in this form not part of A'Hearn's (2004) paper. A'Hearn (2004, p.14) stated that the bias of the restricted estimator is *"[...] increasing very rapidly as the σ-restriction error exceeds 0.5 cm"*. Yet, A'Hearn (2004) seems to refer to the *squared* bias, so the direction of this bias is not discussed. In one aspect, we agree with A'Hearn (2004, p.14): The bias does not change substantially as the sample size is varied.

The bias of the restricted estimator is almost a linear function of the deviation from the σ-restriction (figure 5): If the imposed standard deviation is larger than the standard deviation in the population, α is underestimated in our simulations. The opposite is true if the imposed standard deviation is smaller than the population standard deviation. In this case, α is overestimated. Furthermore, the bias increases in absolute terms as the truncation point increases. However, we advise the reader not to generalize these findings to restricted other TNR estimations not simulated here. Due to the non-linear nature of the estimation, we do not know whether the bias behaves similarly in other settings.

Figure 5: Bias of the RTNR



Sources: See the text. *Notes:* N=500. Bias of the restricted estimator is defined as $Bias(\hat{\theta}|\theta) = E(\hat{\theta} - \theta)$ where $\hat{\theta}$ denotes the estimator and θ denotes the population parameter. Biases for truncation points between 159 and 167 are not shown. These biases lie between the two lines shown.

4.4.2. Extension to a linear model with an explanatory variable

In this section, we extend A'Hearn's (2004) model to a linear model that contains a single explanatory variable in addition to a constant. In our simulations, we now consider the population model

$$y^* = \alpha + x\beta + u$$

where α is the constant, $x{\sim}N(\mu, \delta^2)$ and $u{\sim}N(0, \sigma^2)$, independent of x. To specify a model in such a way is not unique. For example, the expectation of y^* depends on α, β and μ So, in a sense it is redundant to include α when $\mu \neq 0$ and $\beta \neq 0$, because any expectation of y^* could be realized using only β and μ. However, we chose the specification that includes α, because it is uncommon in anthropometric applications to estimate models that exclude a constant[18]. The model with an explanatory variable contains two new sources of variation compared to A'Hearn's (2004) model: μ and δ. We first examine the influence of δ. We simulate the linear model with explanatory variable using the following values for the parameters: $\alpha = 159, \beta = 2, \mu = 3$. δ ranges from 1 to 5 in steps of 1. All other parameters were identical to the values in 4.1. The mean of y^* is

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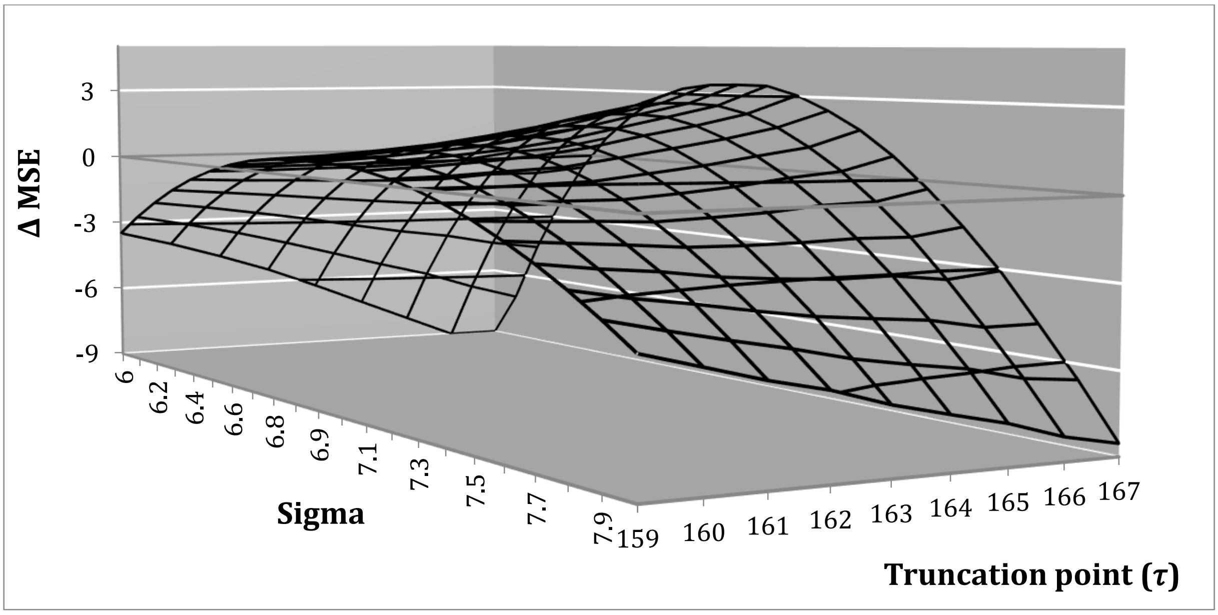
[18] By the same logic, any mean of y^* could be realized by standardizing μ to zero. However, standardized explanatory variables are also uncommon in anthropometric work, so we consider the possible influence of the parameter μ to be of importance, too.

therefore still 165, as in the constant only model. Yet, because y^* is now a sum of two random variables, its variance is $var(y^*) = var(159 + 2x + u) = 4var(x) + var(u)$. Note that u is homoscedastic. What is estimated by the TNR is still the standard deviation of u, not the overall standard deviation of y^*. We consider this approach to me more appropriate than keeping the overall standard deviation of y^* constant. Such an approach would imply that when the variance of x changes, one would have to vary the standard deviation of the error term *simultaneously*. Interpretation and comparison of such simulations would be much more complicated than the approach we pursue. The case where x is not random, reduces to the constant only model. We again use Wallace's (1972) weak MSE criterion to identify the region where the restricted estimator is superior to the unrestricted one. In the case of the linear model with explanatory variable, the weak MSE criterion is the sum of the mean square errors of the constant, the slope parameter β and σ. Our simulations yield the following results: The shape of the MSE differences is similar to the one in the constant only case (figure 6).

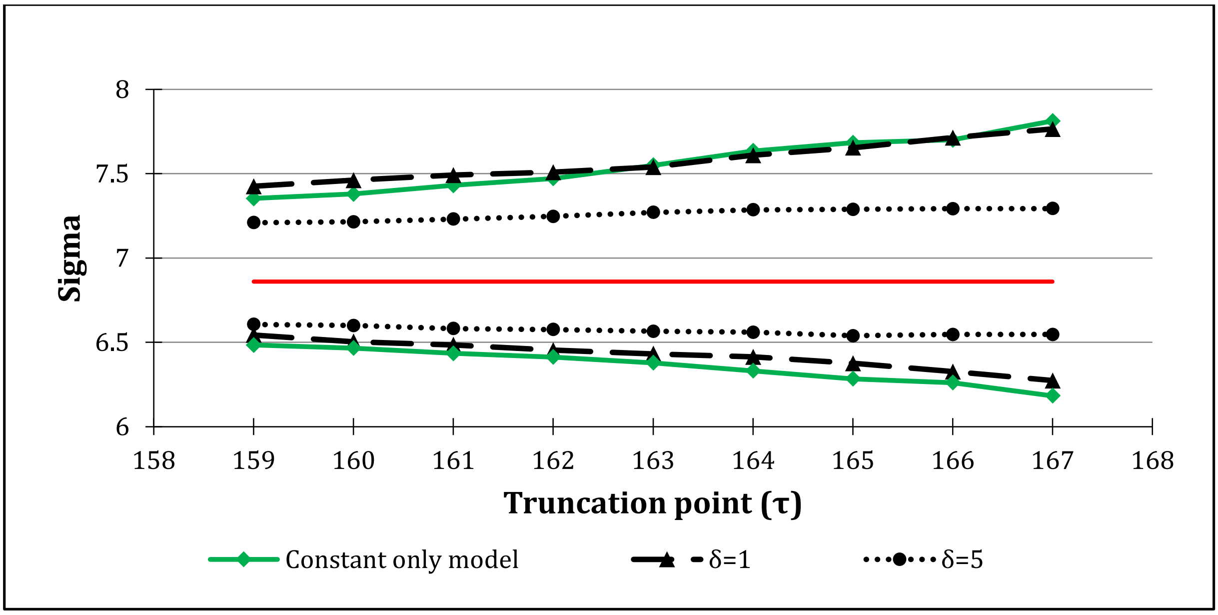
Figure 6: MSE simulation results



Sources: See the text. *Notes:* Simulation results for the linear model. N=500, $\delta = 3$.

As in the constant only case, the restricted estimator performs better in a region around 6.86 and the difference in MSE becomes larger as the truncation point increases (figure 7). An increase in the variation of the covariate x leads to a reduction of the region where the restricted estimator should be applied (figures 7).

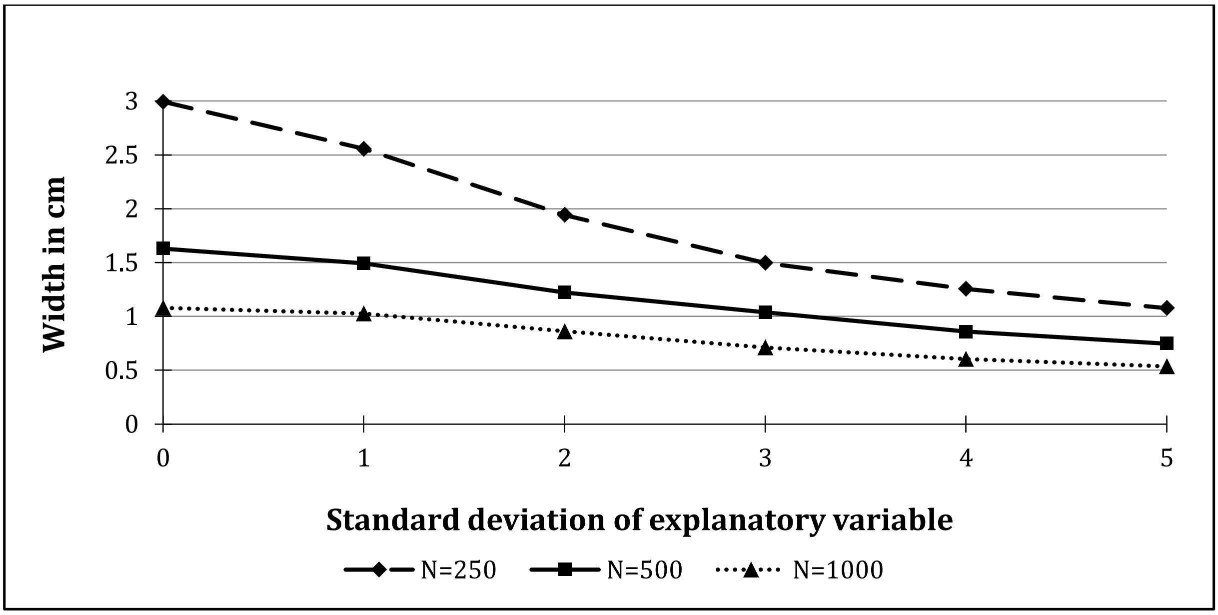
Figure 7: Boundaries of superiority of the RTNR



Sources: See the text. *Notes:* N=500. Red line: $\sigma = 6.86$ Lines above the solid red line are upper bounds. Lines below the solid red line are lower bounds. All combinations of σ and τ that are below the upper bound and above the lower bound are those combinations of σ and τ where the restricted estimator is superior to the unrestricted one. Constant only results are taken from section 4.1

In particular, the reduction is most noticeable in situations where – in the constant only model - the restricted estimator is clearly preferred: When the truncation point is high and the sample size is small. This effect, however, is not linear in the variation of x (figure 8). As in the constant only case, an increase in the sample size leads to a shrinkage of the region of superiority (figure 8). The extent of this shrinkage depends on the variation in the regressor: The effect of the sample size is bigger for smaller variations in the regressor (figure 8)

Figure 8: Width of region where the RTNR is superior



Sources: See the text. *Notes:* MSE for τ =167 shown. δ=0 refers to the constant only model from section 4.1.

As far as the individual contribution to ΔMSE is concerned, the overall pattern is identical to the constant only model (figure 9): The constant estimate has the biggest influence on the relative performance of the estimators. The estimate of σ contributes only little to ΔMSE. Interestingly, the estimate of the slope parameter also has only little effect on the relative performance, too. So, the superiority of the restricted estimator in case of a linear model with an explanatory variable is for the most part caused by the estimate of the constant, just as in the constant only case.[19] The magnitude of ΔMSE decreases in the variation of the regressor x (figure 9). Remarkably, the relative performance of the constant estimators is also influenced by this variation in the regressor.

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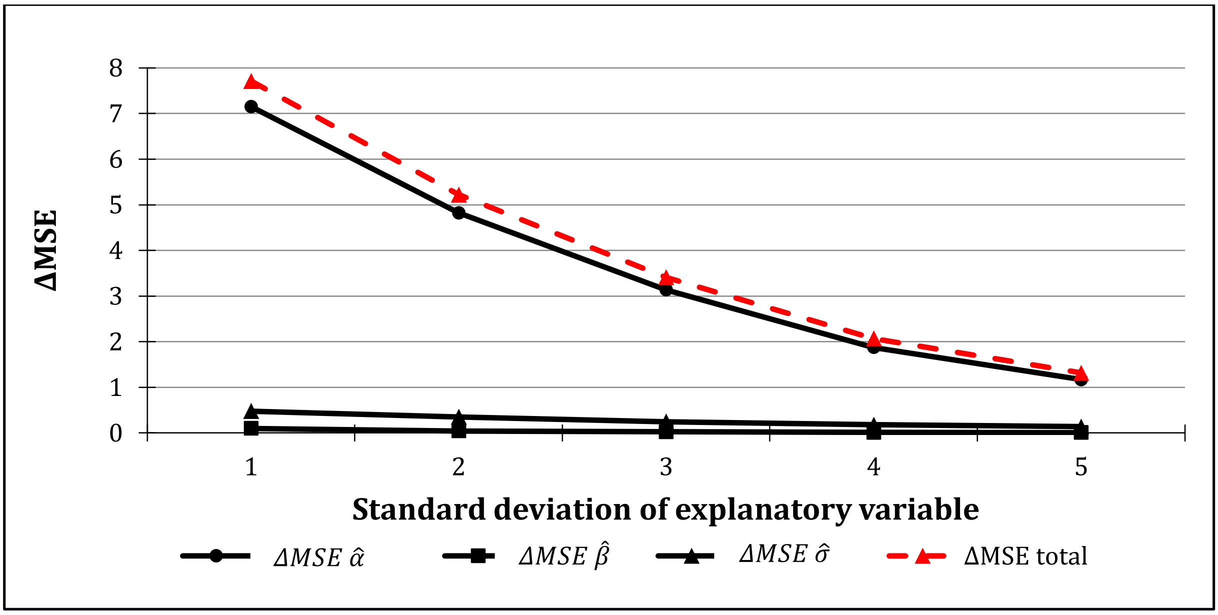
[19] We investigate whether the small contribution of the slope parameter to ΔMSE is a result of the relative size of the slope parameter relative to the size of the constant in the following section.

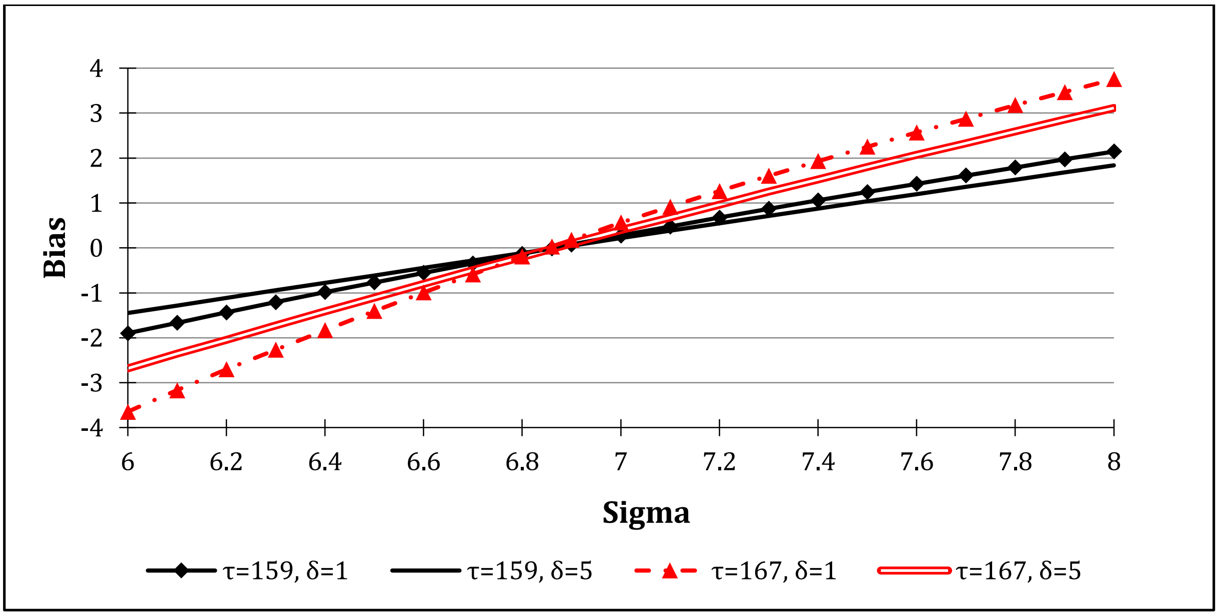
Figure 9: Maximum of ΔMSE



Sources: See the text. *Notes:* N=500. ΔMSE refers to the difference in MSE of the unconstrained minus the MSE of the restricted model. The maximum is calculated on the basis of all values of σ and τ for the respective standard deviations of the regressor.

The bias of the constant of the restricted estimator behaves similarly to the bias in the constant only case (figure 10). The bias of the constant does not vary with the number of observations and its direction is identical to the constant only case, too. Compared to the constant only case, the bias of the constant is generally larger. Nevertheless, the bias of the constant decreases when the standard deviation of x increases.

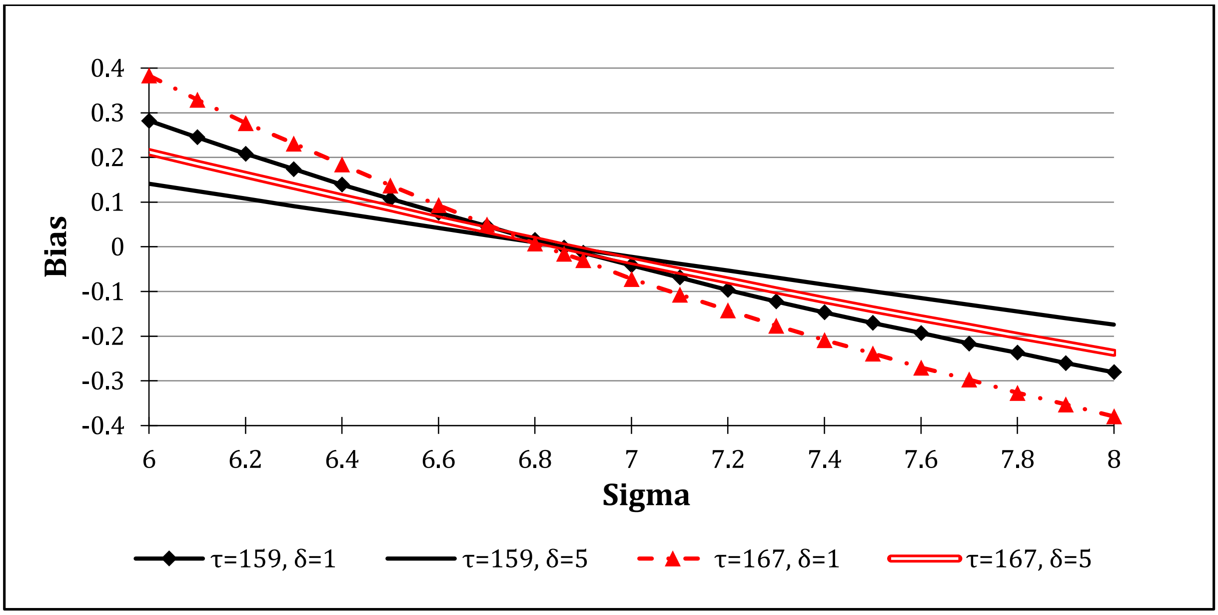
Figure 10: Bias of the RTNR constant estimate



Sources: See the text. *Notes:* N=500. Bias of the restricted estimator is defined as $Bias(\hat{\theta}|\theta) = E(\hat{\theta} - \theta)$ where $\hat{\theta}$ denotes the estimator and θ denotes the population parameter. Biases for truncation points between 159 and 167 are not shown.

Surprisingly, the direction of the bias is reversed for the estimate of the slope parameter, compared to the constant (figure 11). In all other aspects, the estimator of the slope parameter behaves like the estimator for the constant.

Figure 11: Bias of the RTNR slope parameter estimate



Sources: See the text. *Notes:* N=500. Bias of the restricted estimator is defined as $Bias(\hat{\theta}|\theta) = E(\hat{\theta} - \theta)$ where $\hat{\theta}$ denotes the estimator and θ denotes the population parameter. Biases for truncation points between 159 and 167 are not shown.

4.4.3. Model with a negative slope parameter

We simulated a linear model using the parameter values $\beta = -2, \mu = -3$. In all other aspects, the structure of the simulation is identical to the structure of the model in section 4.2.

The results do not change substantially compared to the results in the preceding section. Only two differences are worth mentioning: The bias of the slope parameter in the restricted case behaves the opposite way[20]. compared to the case where the slope parameter is positive (figure 12).

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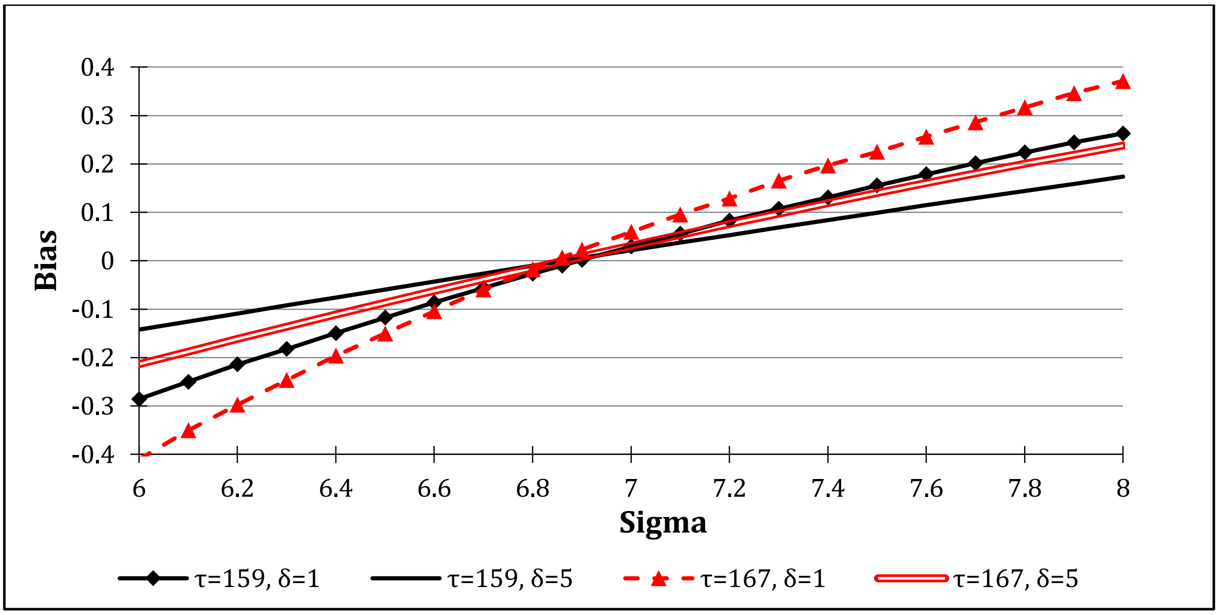
[20] But note that underestimation in the context of a negative parameter means that the estimated parameter is *smaller* than the true one, implying that it is *larger* than the true parameter in absolute terms. For example, the estimated slope parameter is -2.29 if the true standard deviation of the error term is 6 (N=1000 δ=1, $\tau = 159$).

Figure 12: Bias of the RTNR slope parameter estimate



Sources: See the text. *Notes:* N=500. Bias of the restricted estimator is defined as $Bias(\hat{\theta}|\theta) = E(\hat{\theta} - \theta)$ where $\hat{\theta}$ denotes the estimator and θ denotes the population parameter. Biases for truncation points between 159 and 167 are not shown.

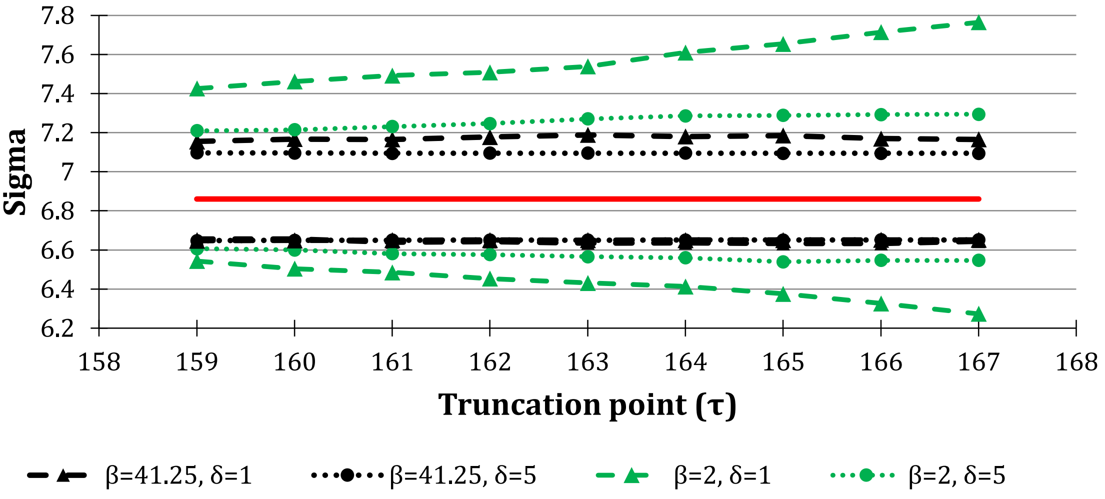
Another difference is the magnitude of ΔMSE. It is generally a bit larger than in the case of a positive slope parameter. But the overall pattern is identical to the results in section 4.2. The constant contributes most to ΔMSE, and ΔMSE decreases with an increasing variation of the regressor. The estimates of the slope parameter and of σ contribute little to ΔMSE.

4.4.4. Model with large slope parameter

In this section, we investigate whether the relative magnitude of the estimated parameters (intercept and slope) has an influence on the relative performance of the estimators. We again simulate a linear model that contains an explanatory variable and a constant. Now, the parameter values are: $\alpha = \beta = 41.25$. The setup is in all other aspects identical to the setup in section 4.2. Note this combination of parameter values may not be encountered in applied work, where usually the constant is large relative to the slope parameters (in particular, if *x* is a birth cohort dummy). However, to simulate regressions using this parameter combination may be informative to explore whether the estimated differences in MSE performance are scale dependent or not.

The region where the restricted estimator is superior to the unrestricted estimator is now smaller than in section 4.2 (figure 13). There is another difference to the results from preceding section: An increase in the truncation point does not a have an influence on the relative performance of the estimators (figure 13), the boundaries that characterize the region of superiority remain virtually constant when the truncation point changes.

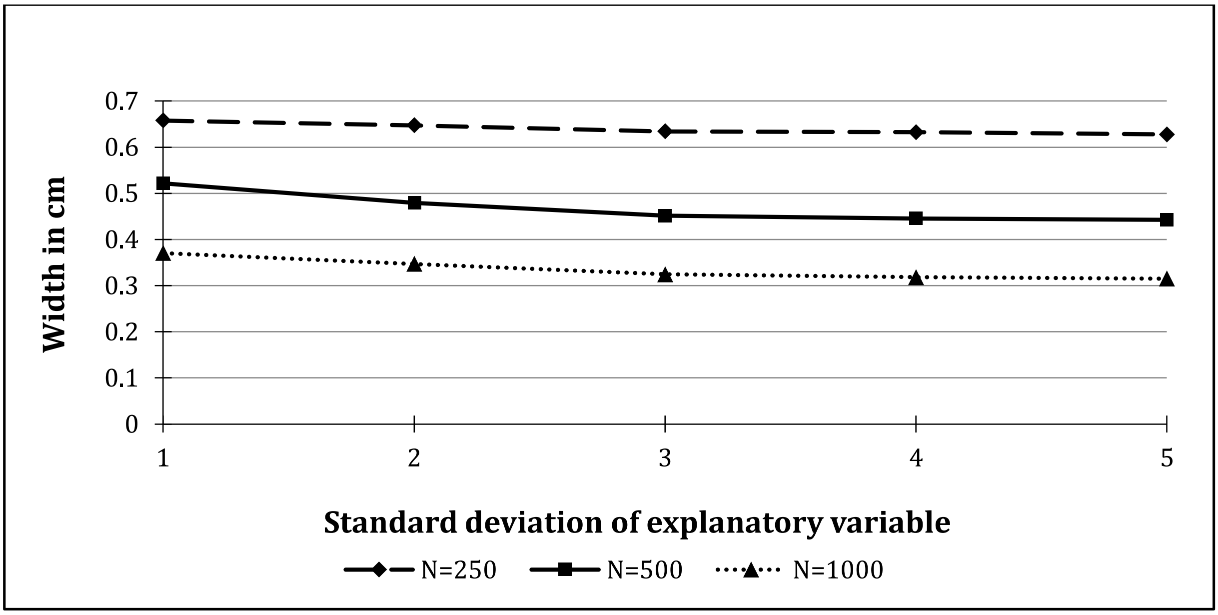
Figure 13: Boundaries of superiority of the restricted estimator



Sources: See the text. *Notes:* N=500. Red line: $\sigma = 6.86$ Lines above the solid red line are upper bounds. Lines below the solid red line are lower bounds. All combinations of σ and τ that are below the upper bound and above the lower bound are those combinations of σ and τ where the restricted estimator is superior to the unrestricted one. Results for β=2 are taken from section 4.2

Similar to the previous results, the region where the restricted estimator performs superior decreases with an increasing sample size (figure 14). Yet the effect is very small compared to the effect in section 4.2 (figure 8), and the effect varies only little with the standard deviation of the regressor.

Figure 14: Width of region where the RTNR is superior



Sources: See the text. *Notes:* MSE for τ =167 shown.

In addition, the restricted estimator is not substantially superior to the unrestricted estimator any more. The biggest difference in MSE is only 0.6 for a sample size[21] of 250. The variation in the regressor only has an effect on ΔMSE for small standard deviations, not for larger ones. Contrary to the results in section 4.2 (figure 8), the estimate that contributes most to ΔMSE is not always the constant. The constant estimate only dominates ΔMSE for lowest standard deviation of the regressor, but not for larger variations in the regressor (figure 15). In cases of a more variable regressor, the estimate of σ dominates ΔMSE.

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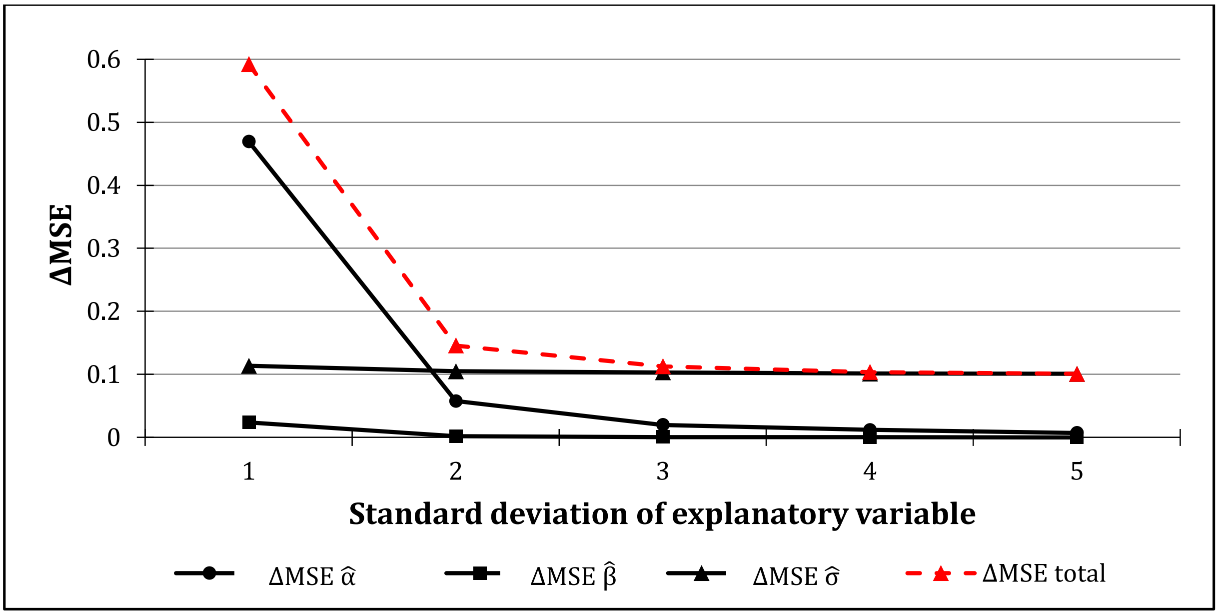
[21] The biggest difference is even smaller for larger sample sizes.

Figure 15: Maximum of ΔMSE



Sources: See the text. *Notes:* N=250. ΔMSE refers to the difference in MSE of the unconstrained minus the MSE of the restricted model. The maximum is calculated on the basis of all values of σ and τ for the respective standard deviations of the regressor.

From these results we conclude that the superiority of the restricted estimator depends on the magnitude of the constant. Because here the restricted estimator does not perform superior compared to the unrestricted estimator in this setup, we do not discuss its bias.

4.4.5. Beta only model

In this section, we present the results of a model without an explicitly included constant[22], but where a slope parameter (and σ) to be estimated. This model will hardly be encountered in applied anthropometric work, but the simulation of this parameter combination can yield insights into the behavior of the estimator under special circumstances. We chose $\beta = 55$. The setup is in all other aspects identical to the setup in section 4.2.

The results are almost identical to the results in section 4.4. The small effect that the variation in the regressor still had in that section, is now completely absent (figure 16).

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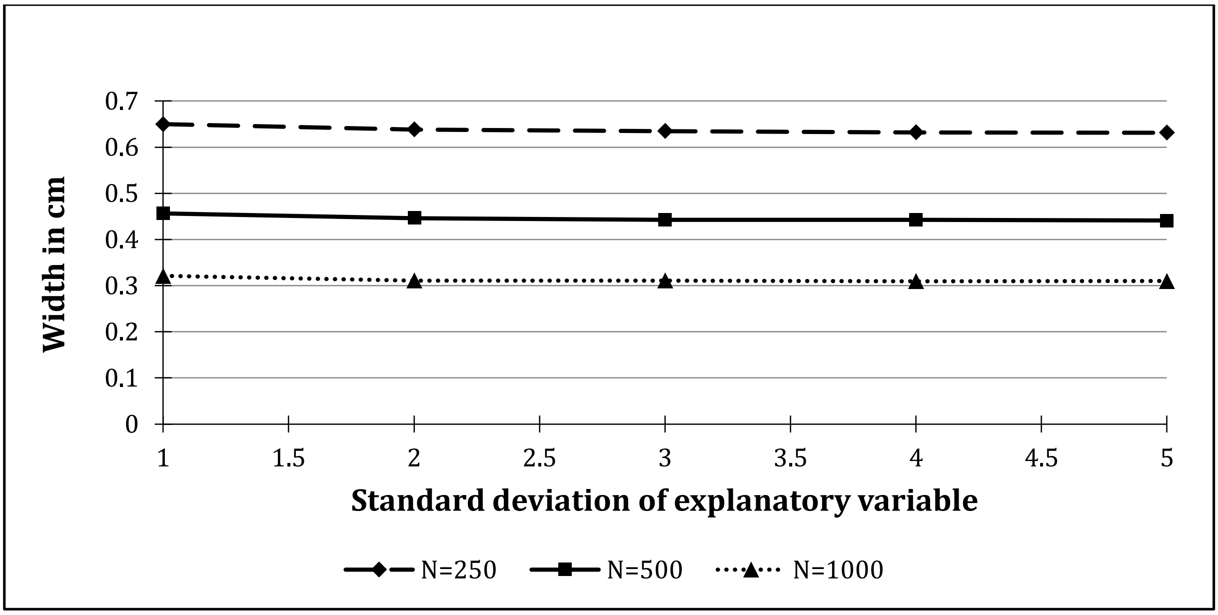
[22] Note that this does not imply that y^*has a mean of zero. As we discussed in section 3.4.1, the explanatory variable is not standardized.

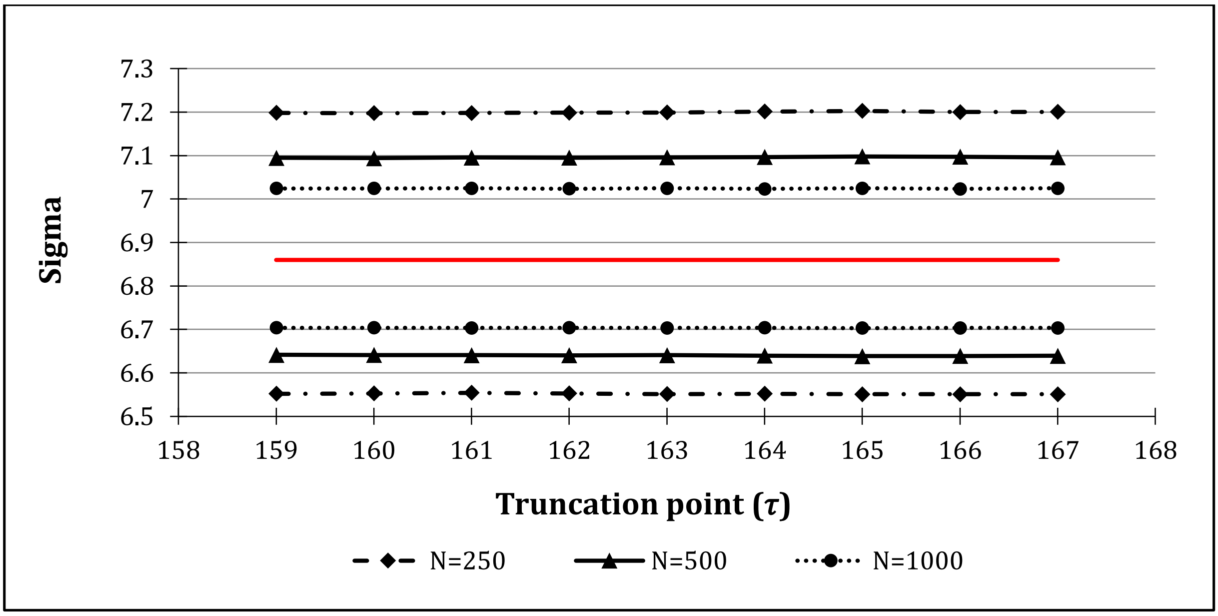
Figure 16: Width of region where the RTNR is superior



Sources: See the text. *Notes:* MSE for τ =167 shown.

The only characteristic of the sample that still has an effect is the sample size (figure 17). The direction of the effect is the same as in the other simulations.

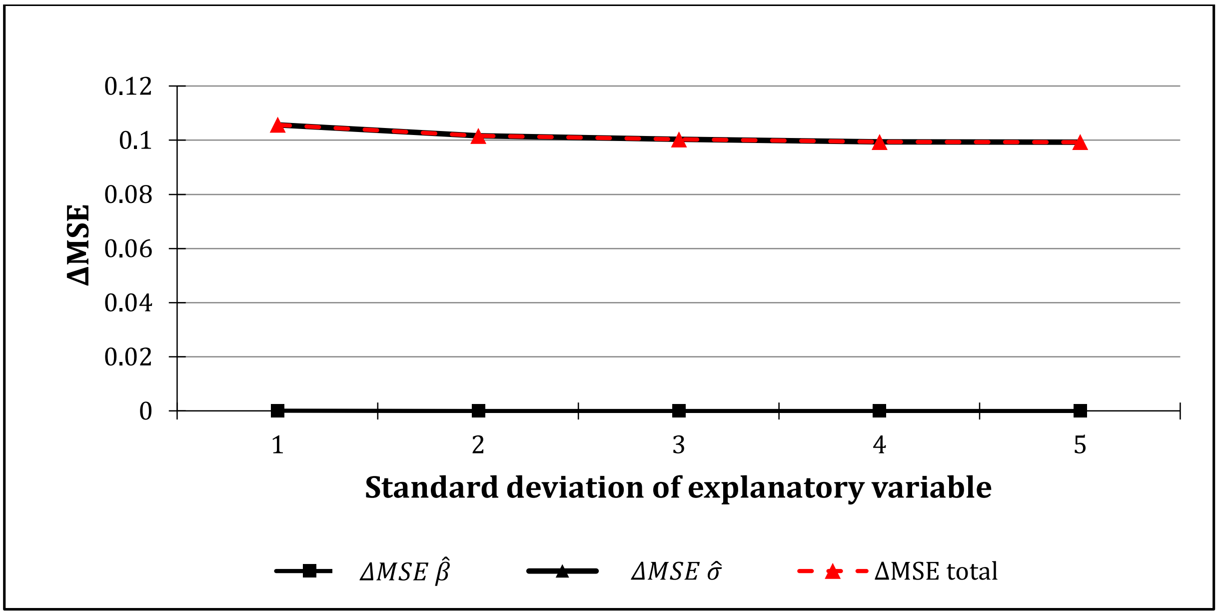
Figure 17: Boundaries of superiority of the restricted estimator



Sources: See the text. *Notes:* Red line: $\sigma = 6.86$, Lines above the solid red line are upper bounds. Lines below the solid red line are lower bounds. All combinations of σ and τ that are below the upper bound and above the lower bound are those combinations of $\sigma$and τ where the restricted estimator is superior to the unrestricted one. Results for $\delta = 1$ shown.

The maximum difference in MSE is now even lower than in section 4.4. The restricted estimator is consequently not superior to the unrestricted estimator in a model without a constant. When no intercept is included in the model, the difference in MSE is clearly dominated by the influence of the estimate of σ (figure 18). In estimating the slope parameter, the restricted and the unrestricted estimator are identical[23].

Figure 18: Maximum of ΔMSE



Sources: See the text. *Notes:* N=250. ΔMSE refers to the difference in MSE of the unconstrained minus the MSE of the restricted model. The maximum is calculated on the basis of all values of σ and τ for the respective standard deviations of the regressor.

4.4.6. Variation in the mean of the regressor

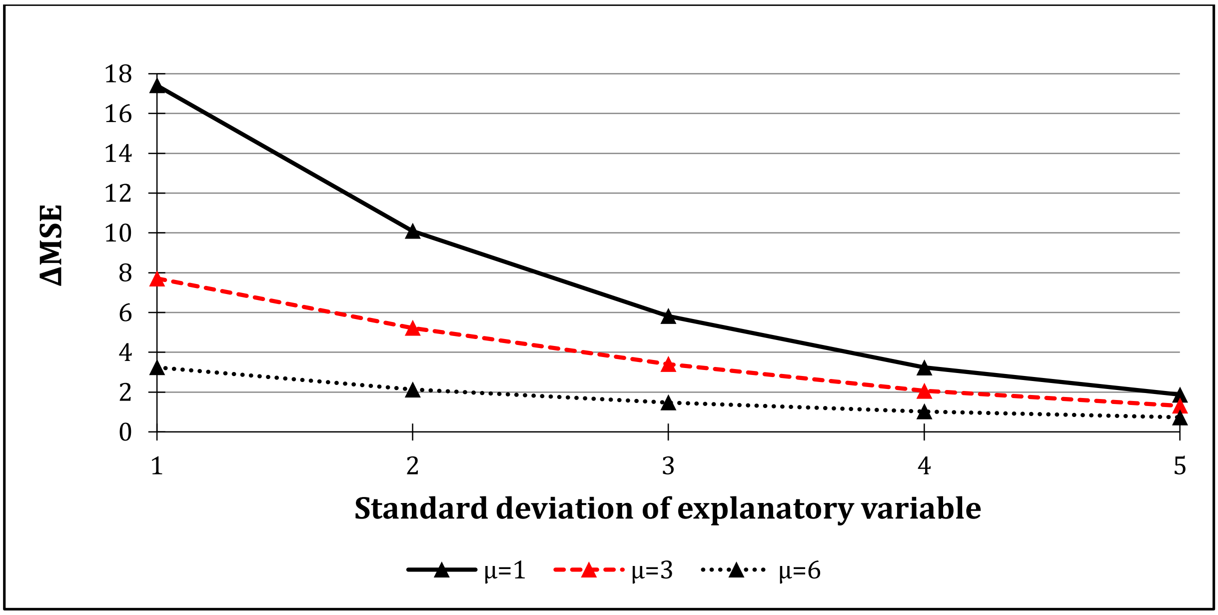
In this section, we vary the mean of the regressor x in order to determine whether the relative performance of the estimators is influenced by it. We simulate the linear model using the following values for the parameters: $\beta = 2$, δ ranges from 1 to 5 in steps of 1. μ takes values 1,2,3 and 6. The constant was adjusted in each of the parameter combinations to ensure that the overall mean of y^* remained at 165.

Our results indicate that the superiority of the restricted estimator decreases with an increase in the mean of the regressor, with the effect of an increase in the mean of the regressor is strongest when the standard deviation of the regressor is low (figure 19).

---

[23] There still exists a positive difference between the restricted and the unrestricted estimator, but its size is 0.00014 at maximum

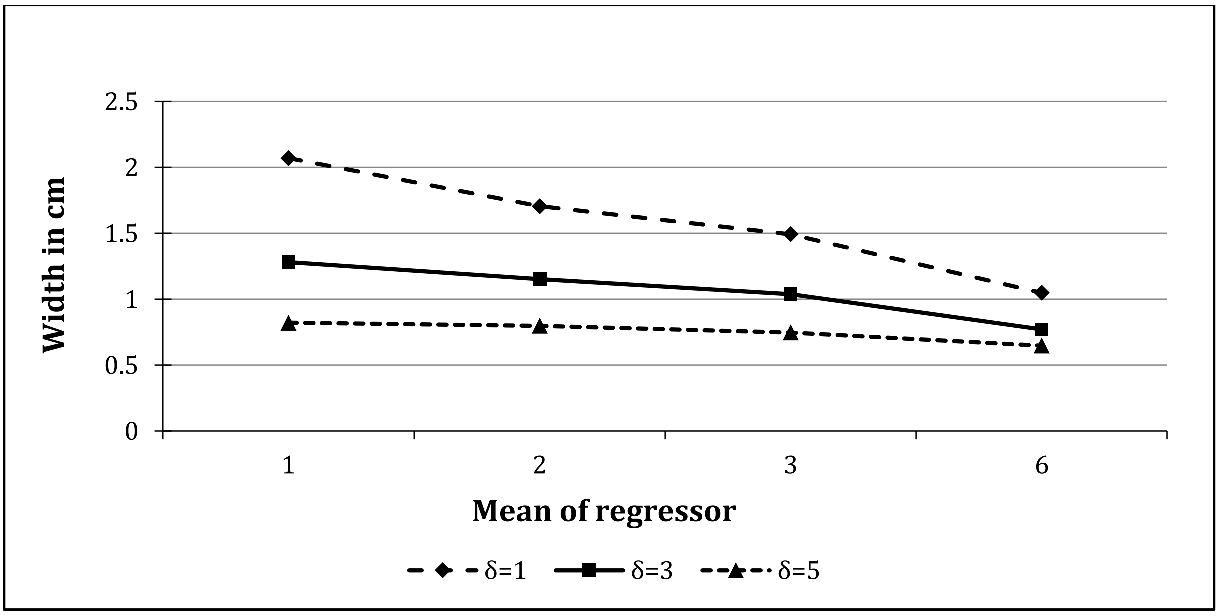
Figure 19: Maximum of ΔMSE



Sources: See the text. *Notes:* N=500. ΔMSE refers to the difference in MSE of the unconstrained minus the MSE of the restricted model. The maximum is calculated on the basis of all values of σ and τ for the respective standard deviations of the regressor. Results for μ=2 are between the results for $\mu = 1$ and $\mu = 3$.

The mean of the regressor also has an effect on the range around the σrestriction where the constrained estimator is superior. This region also becomes smaller when the mean of the regressor increases. Similar to the magnitude of ΔMSE, the range decreases most when the standard deviation of the regressor is low (Figure 20).

Figure 20: Width of region where the RTNR is superior



Sources: See the text. *Notes:* N=500. MSE for τ =167 shown.

4.5. Conclusion

A'Hearn's (2004) results concerning the restricted estimator are still valid if Wallace's (1972) weak MSE criterion is used. The fact that the restricted estimator is superior to the unrestricted estimator can largely be attributed to the better estimation of the constant. We have established that the superiority of the restricted estimator carries over to a linear model that includes an explanatory variable. The superiority of the RTNR stems from the better estimate of the constant. In estimating a slope parameter, the constrained estimator does not offer a superior performance compared to the unrestricted estimator. This effect is not markedly influenced by the magnitude of the estimated slope parameter. The region where the restricted estimator is superior is smaller compared to the constant only case. With increasing variability of the covariate, the region of superiority becomes even smaller. With an increase in the mean of the covariate, both estimates become more equal. The difference between the restricted and the unrestricted estimator also depends on the magnitude of the constant. Whether the restricted estimator should be preferred to the unrestricted estimator therefore depends on characteristics of the population model to be estimated. Yet, as the population model is never known, we suggest estimating always both versions of the estimator and comparing their results. Future research should also calculate the variation in the MSE induced by simulating it. It may be that the MSE is simulated with such a high variation that a discrimination between both estimators is not possible.

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Zehetmayer, Matthias. 2011. "The continuation of the Antebellum Puzzle: Stature in the US, 1847–1894" *European Review of Economic History 15:2,* 313–327

Software used:

STATA 12.0 StataCorp. 2011. *Stata Statistical Software: Release 12*. College Station, TX: StataCorp LP.

Random seed for simulations: 47586315

Appendices

5. Appendix to chapters 1 and 2

5.1. Definitions and concepts used to define the Holy Roman Empire and supplementary sources consulted

Our definition of the HRE does not exactly correspond to the strict definition of the Empire between 1648 and 1789. Several restrictions and extensions apply: Firstly, all Italian territories that were formally part of the Empire are excluded. This pertains, for example, to Habsburg possessions like the Duchy of Milan. In this respect, our definition corresponds to the Empire in the borders defined in (Leisering[1] 2009). We decided to include the Duchy of Lorraine and the Landgraviate of Alsace in our regressions. Although both territories became part of[2] France between 1648 and 1766, they were included because of their long-standing cultural and political ties to the HRE, as well as their geographic proximity.

In the geocoding process we carried out, every observation was assigned to a sovereign territory within the Empire, where feasible. To reduce the heterogeneity of the geographic information to a meaningful level, for our analysis, we assigned every territory to the corresponding Imperial Circle[3], were possible, based on the information in (Köbler 2007). In cases where a territory was not part[4] of a circle, we assigned such territories to the circle that we considered geographically adequate.

Since the territories of noble houses tended to be divided up in times of inheritances, the Empire was, at least in some regions, extremely fragmented. To control for within-circle heterogeneity, we had to define adequate larger territorial units. Guided by the maps in (Leisering 2009) and using common sense, we combined territories of individual

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[1] We refer to the following map; p.82-83: "Mitteleuropa bei Beginn der Französischen Revolution".

[2] The Alsace was gradually conquered by the King of France by 1697, but was culturally still part of the Empire (Köbler 2007, p.164). The Duchy of Lorraine formally became part of the Kingdom of France in 1766, but was de facto part of France from 1738 on (Köbler 2007, p.392).

[3] "Reichskreis". Imperial Circles were defined in 1500 and modified in 1512. They were supposed to organize *"Frieden, Gericht, Verteidigung und Steuern im Reich gebietsweise"* (Köbler 2007, p.559).

[4] The prime examples in our data are the territories of the "Imperial Knights". We assigned territories of the "Imperial Knights" in the Rhineland region to the "Upper Rhenish Circle", territories in Swabia to the "Swabian Circle" and so on. This assignment does not correspond to the political organizational structure of the "Imperial Knights", but we considered a geographic assignment more adequate than a political one.

branches of noble houses into one category where necessary[5]. Territories jointly governed by more than one landlord were assigned to the landlord with the highest rank[6].

While we cannot exclude small and unintentional deviations from exact definitions of the circles due to our available source material, we made one deliberate choice to extend the definition of one of our circles: What we designated as the Upper Saxon Circle contains territories that were not part of the actual circle, but were also governed by the House of Hohenzollern. Our definition of the Upper Saxon Circle thus includes Western and Eastern Prussia[7](see figure A1), as well as all Free Cities within these regions. One reason for this decision was that the years of enlistment extended into a period of time when the First Partition of Poland had already happened (1772). So it is possible that, during enlistment recruits from this region simply stated that they were “born in Prussia”. The second reason is that this definition of the Empire ensures that our estimates are comparable to research on Germany that pertains to later historical periods. Finally, we extended the definition of the Imperial Circle in order not to discard the respective observations. This did not influence the estimation results[8]. Furthermore, we included N=44 observations from Lusatia in the Upper Saxon Circle, or to be more precise we added the observations to the Electorate of Saxony. Formally, Lusatia was a Bohemian fiefdom, but it was ceded to Saxony in the 17th century (Köbler 2007).

---

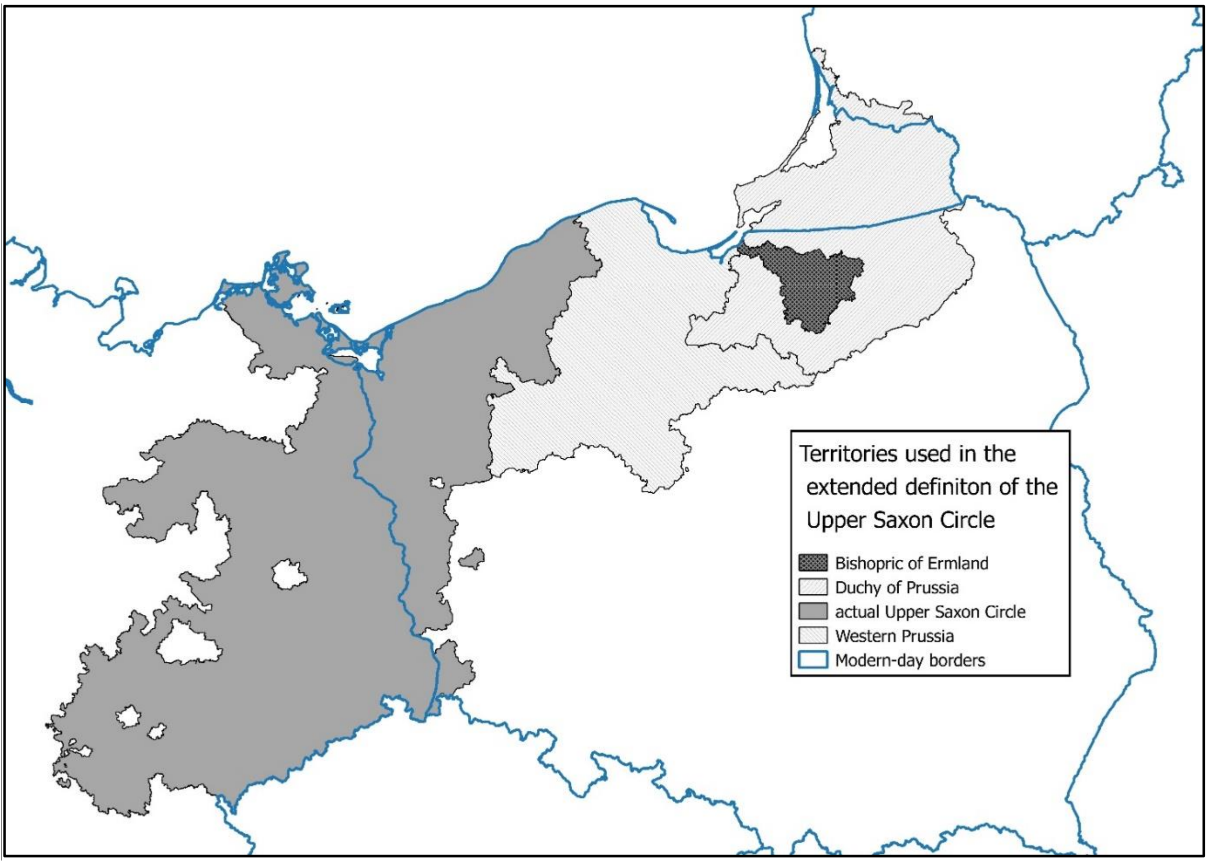
[5] For example, we combined all the individual territories of “Hesse”. The sheer number of individual territories illustrates why this procedure was necessary. “Hesse” in the 18th century could be split up into: Hessen-Darmstadt, Hessen-Kassel, Hessen-Homburg, Hessen-Rothenburg (a semi-independent territory), as well as the territories that were inherited in 1736, these are Hanau-Lichtenberg and Hanau-Münzenberg (via Hanau-Lichtenberg). See Köbler (2007) for details. This territorial fragmentation can be generalized to most parts of the Empire (in particular the South-West). Due to this shattered political landscape, the corresponding numbers of observations for each of the individual territories would be very low. Reasonable results cannot be expected unless a form of aggregation is carried out.

[6] For example, a territory that was under joint sovereignty of some “Imperial Knight” and the “Elector of Trier” would be assigned to the “Electorate of Trier”. We carried out the assignment this way irrespective of the actual share of the territory that a landlord possessed. In case of ties in rank, the assignment was random.

[7] Consisting of the Bishopric of Ermland and the Duchy of Prussia. The Duchy of Prussia was governed by the Hohenzollerns since 1618, see Köbler (2007) for details.

[8] The number of observations from these territories is quite small and the inclusion does drive our results (no more than N=60 for the Duchy of Prussia, N=59 for Danzig, N=5 for Elbing, N=6 for Ermland, N=1 for Western Prussia). The predicted trends for the East region as well as the trends for entire HRE were qualitatively unaffected when these observations were discarded.

Figure A1: Extended definition of the Upper Saxon-Circle



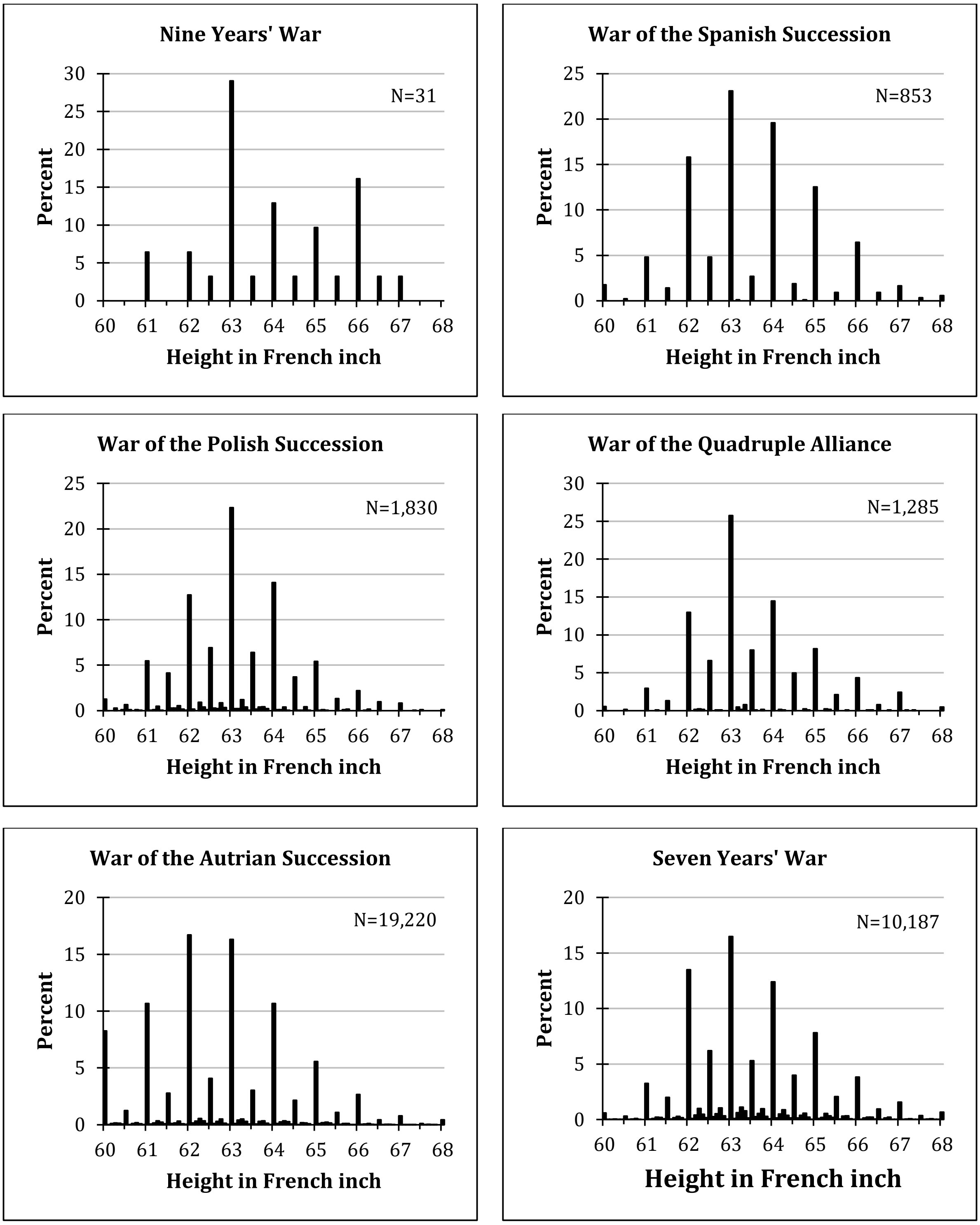
Sources: See the text. Maps are our own creation in QGIS based on existing shapefiles. *Sources and copyrights for the map:* See references. *Notes:* Free Cities not shown.

Finally, it should be noted that our definition of the Burgundian Circle includes N=127 observations for the city of Maastricht. The city was conquered by the United Provinces but was claimed by the Duchy of Brabant and the Bishopric of Liège (Köbler 2007). The predicted trends for the Central-West region as well as for the Empire as a whole were unaffected when these observations were discarded.

5.2. Additional descriptive statistics and histograms

This section contains separate histograms of height for enlistment during one of the wars mentioned in the main text. Note that observations below 60 Fi (162.4 cm) and observations above 68 Fi (184.1 cm) are not shown.

Figure A2: Histograms of height for enlistment during a specific war:

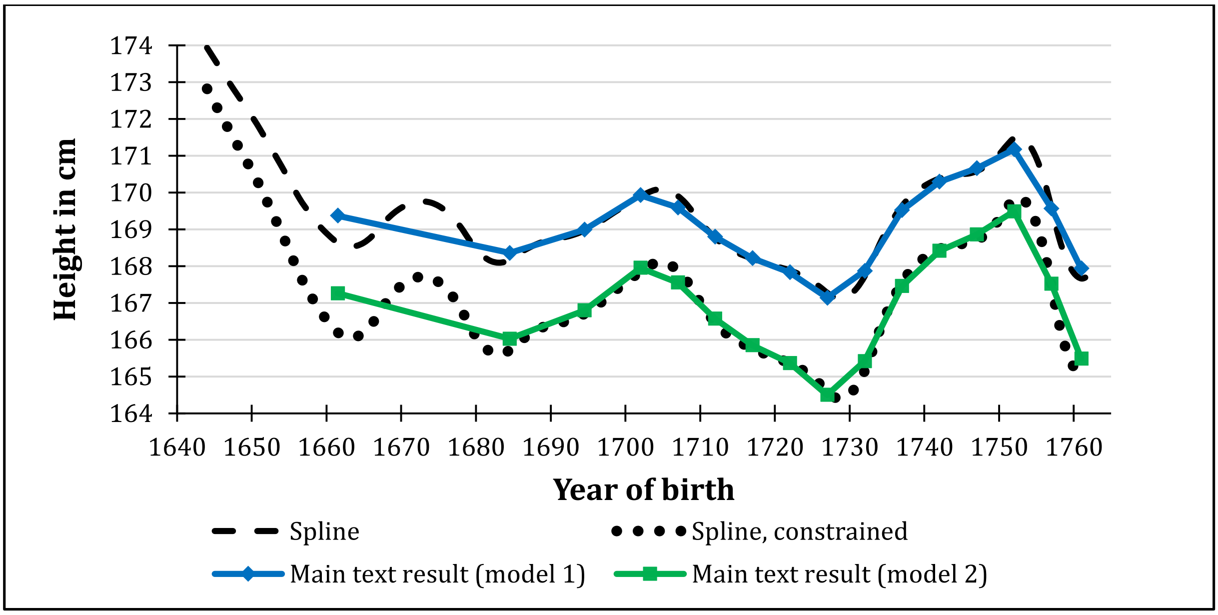


5.3. Regressions and robustness checks not presented in the main text

5.3.1. Additional spline regression

The spline estimations we used in addition to the dummy variable approach react somewhat sensitive to a combination of very early years of birth and a correspondingly small sample size for these years. The resulting predictions can occasionally produce unconvincingly high or low levels of height. We observed this behavior of the spline regressions in unconstrained as well as constrained regressions. Consequently, we restricted the years of birth in all spline regressions in the main text where necessary. Figure A3 provides an example of such irregular predictions for early years of birth.

Figure A3: Predicted heights of soldiers born in the HRE based on a spline regression using the full range of years of birth



Sources: See the text. *Notes*: The sample used in our calculations consists of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

5.3.2. Alternative truncation point for Grenadiers

We re-estimate models 1 and 2 using a truncation point of 64 Fi (173.2 cm) for all Grenadiers and 62 Fi (167.8 cm) for all other troops. The results using this alternative truncation point were nearly identical to the estimates from the main text (table A1, figure A4). The estimated coefficient of the Grenadier dummy was larger in the models where the truncation point was constant for all Grenadiers compared to the models where the truncation point varied with the age of the Grenadiers. However, the estimated coefficients were still of sensible magnitude (table A1).

Table A1: Estimation results, alternative truncation point for Grenadiers

Dependent variable: Height in cm	Main text results			Alternative truncation point		
	(1)	(2)	N	(A1)	(A2)	N
Troop category						
Light troops	-1.9***	-2.4***	1,240	-2.0***	-2.5***	1,240
Lieut. Colonelle	0.7***	0.8***	4,260	0.7***	0.8***	4,260
Colonelle	4.3***	5.2***	6,421	4.3***	5.2***	6,421
Grenadiers	4.8***	4.3***	2,123	6.1***	6.3***	2,467
Infantry	Ref.		50,799	Ref		50,799
Age						
Age 16	-6.1***	-7.6***	2,045	-5.8***	-7.3***	2,075
Age 17	-6.0***	-7.5***	4,380	-5.8***	-7.3***	4,421
Age 18	-4.3***	-5.3***	6,433	-4.1***	-5.2***	6,472
Age 19	-2.8***	-3.5***	6,238	-2.7***	-3.3***	6,293
Age 20	-1.9***	-2.4***	6,485	-1.9***	-2.3***	6,545
Age 21	-0.8***	-1.0***	4,576	-0.7***	-0.9***	4,614
Age 22	-1.2***	-1.5***	5,106	-1.1***	-1.3***	5,141
Age 23	-0.7***	-0.9***	4,146	-0.7***	-0.9***	4,192
Age 24-50	Ref.		25,434	Ref.		25,434
Birth cohort						
1644-1679	-0.6	-0.7	274	-0.5	-0.6	274
1680-1689	-1.6***	-1.9***	1,027	-1.5***	-1.9***	1,027
1690-1699	-0.9***	-1.2***	2,646	-0.9***	-1.1***	2,652
1700-1704	Ref.		2,215	Ref.		2,215
1705-1709	-0.3	-0.4	2,324	-0.3	-0.4	2,324
1710-1714	-1.1***	-1.4***	2,957	-1.1***	-1.4***	2,958
1715-1719	-1.7***	-2.1***	4,375	-1.7***	-2.1***	4,383
1720-1724	-2.1***	-2.6***	6,988	-2.1***	-2.6***	7,014
1725-1729	-2.8***	-3.5***	7,250	-2.8***	-3.5***	7,265
1730-1734	-2.1***	-2.5***	5,352	-2.1***	-2.6***	5,370
1735-1739	-0.4*	-0.5*	4,982	-0.5**	-0.5**	5,041
1740-1744	0.4*	0.5*	4,444	0.3	0.4	4,489
1745-1749	0.7***	0.9***	4,713	0.7***	0.8***	4,777
1750-1754	1.2***	1.5***	5,783	1.2***	1.5***	5,826
1755-1759	-0.4*	-0.4*	6,702	-0.4*	-0.4	6,748
1760-1763	-2.0***	-2.5***	2,811	-2.0***	-2.5***	2,824
Imperial Circle						
Alsace	Ref.		16,109	Ref.		16,212
Lorraine	1.1***	1.4***	9,837	1.2***	1.5***	9,930

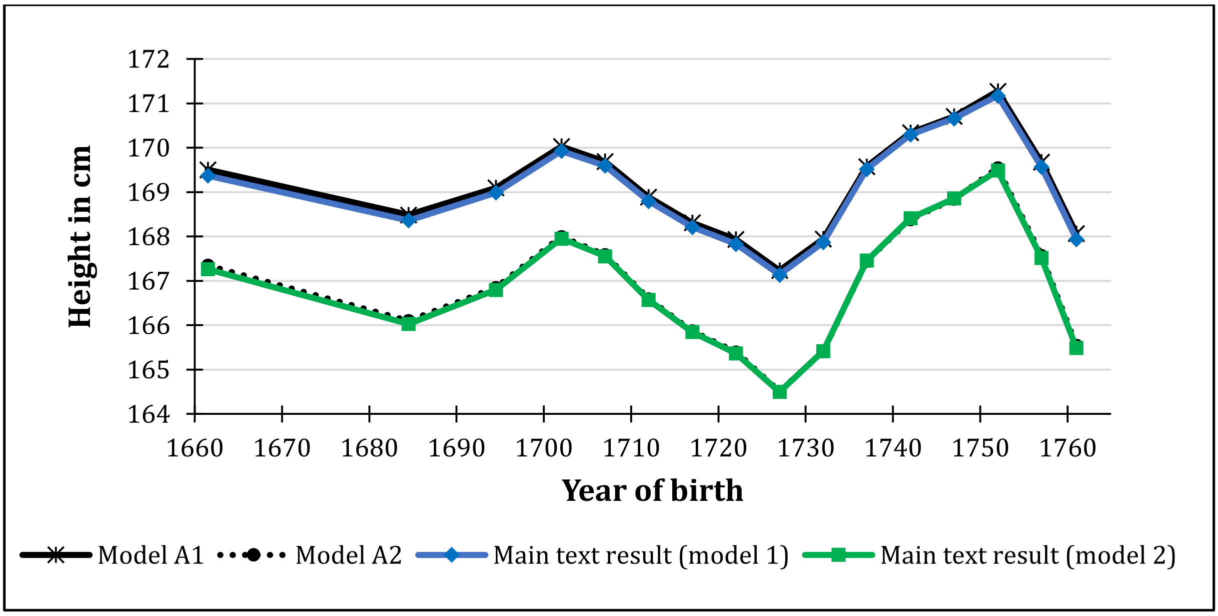
Table continues on the next page

Table A1, continued

Dependent variable: Height in cm	Main text results			Alternative truncation point		
	(1)	(2)	N	(A1)	(A2)	N
Imperial Circle						
Upper Rhine	2.2***	2.7***	8,344	2.2***	2.7***	8,393
Electoral Rhine	2.1***	2.6***	5,854	2.0***	2.5***	5,882
Burgundia	2.2***	2.7***	5,147	2.2***	2.7***	5,168
Swabia	1.2***	1.5***	3,937	1.2***	1.5***	3,953
Westphalia	2.0***	2.5***	3,422	2.0***	2.5***	3,437
Only HRE	1.9***	2.4***	3,040	1.9***	2.4***	3,043
Austria	0.9***	1.1***	2,020	0.9***	1.1***	2,024
Bohemia	0.2	0.2	1,888	0.2	0.3	1,890
Bavaria	1.1***	1.4***	1,856	1.2***	1.4***	1,857
Franconia	0.9***	1.2***	1,518	0.9***	1.2***	1,523
Upper Saxony	1.9***	2.4***	1,150	1.9***	2.4***	1,154
Lower Saxony	2.4***	2.9***	721	2.4***	2.9***	721
Enlistment circumstance						
Enlistment during war	-1.0***	-1.2***	28,138	-1.0***	-1.2***	26,743
Enlistment during peace		Ref.	36,705		Ref.	38,444
Constant	168.5***	166.2***		168.5***	166.2***	
Sigma	5.9***	constrained		5.8***	constrained	
Log-Likelihood	-95,122.6	-95,294.1		-96,020.6	-96,208.0	
N			64.843			65,187

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In models (2) and (A2), Sigma was constrained to 2.534 Fi (6.86 cm).

Figure A4: Predicted height of soldiers born within the HRE: Different truncation points

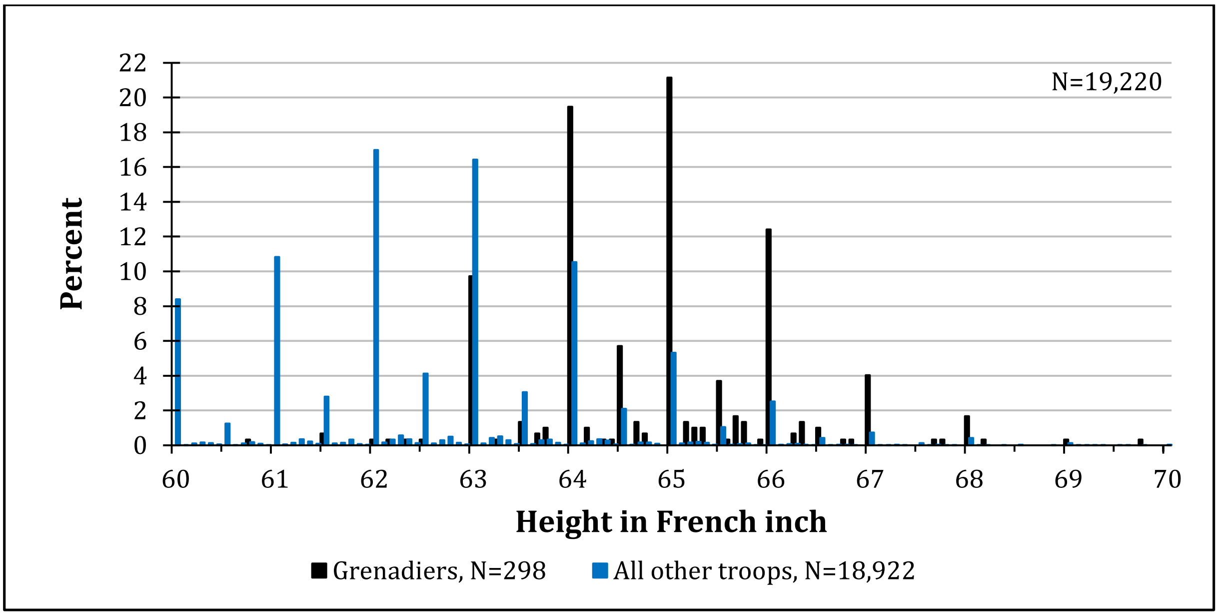


Sources: See the text and chapter 1, table 3, models 1 and 2. *Notes:* The sample used in our calculations consists of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

5.3.3. Alternative truncation point during the War of the Austrian Succession

We cannot rule out with certainty that the MHR was lowered for soldiers who enlisted during the war of the Austrian Succession (figure A5).

Figure A5: Distribution of heights of soldiers who enlisted during the War of the Austrian Succession



Sources: See the text. *Notes:* Observations below 60 Fi (162.4 cm) and above 70 Fi (189.5 cm) are not shown.

We investigated the influence of a variation in the truncation point on the estimation results. We re-estimated models 1 to 4 from table 3 in the main text using a truncation point of 64 Fi (173.2 cm) for all Grenadiers that enlisted during the War of the Austrian Succession, 60 Fi (162.4 cm) for members of all other troops that enlisted during the War of the Austrian Succession and 62 Fi (167.8 cm) for members of all other troops who did not enlist during the War of the Austrian Succession (models A3 and A4). In all regressions, the overall shape of the estimated trends was similar to the models in the main text, but the predicted levels of height increased between 1 and 2.5 cm (table A2, figures A6 and A7). The major difference was that the decline in stature after 1700 is less uniform compared to the trends predicted in the main text, and the significances of birth cohort dummies differ between constrained and unconstrained regressions, to a larger extent than in the main text. This was also true for the regressions that used only observations of adult soldiers (figure A7).

Furthermore, the dummy for enlistment during war has a different sign in unconstrained compared to constrained regressions (models A3 to A6), and was insignificant in the unconstrained regression for adults (models A6). Since this is implausible, combined with the fact that the trends were not as well behaved as the results in the main text, we did not conduct any other regressions with a lower MHR during the War of the Austrian Succession.

Table A2: Estimation results, alternative truncation points during the War of the Austrian Succession

Dependent variable: Height in cm	Adults and youth			Adults		
	(A3)	(A4)	N	(A5)	(A6)	N
Troop category						
Light troops	-1.7***	-2.3***	1,302	-2.8***	-4.1***	317
Lieut. Colonelle	0.7***	0.9***	4,593	0.4**	0.5**	1,645
Colonelle	3.6***	4.7***	6,637	3.1***	4.3***	2,814
Grenadiers	4.9***	3.8***	2,171	4.0***	2.9***	956
Infantry	Ref.		55,058	Ref.		21,221
Age						
Age 16	-5.4***	-7.3***	2,452			
Age 17	-4.6***	-6.2***	4,868			
Age 18	-3.2***	-4.3***	7,028			
Age 19	-2.0***	-2.8***	6,702			
Age 20	-1.3***	-1.8***	6,975			
Age 21	-0.5***	-0.7***	4,905			
Age 22	-0.8***	-1.0***	5,462			
Age 23	-0.5***	-0.7***	4,416			
Age 24-50	Ref.		26,953			
Birth cohort						
1644-1679	-0.8	-1.7**	274	-0.6	-1.7**	253
1680-1689	-1.6***	-2.6***	1,027	-1.3***	-2.6***	967
1690-1699	-1.0***	-1.6***	2,680	-0.7***	-1.4***	1,809
1700-1704	Ref.		2,253	Ref.		1,132
1705-1709	-0.3	-0.2	2,435	-0.9***	-1.1***	1,382
1710-1714	-0.8***	-0.8***	3,170	-0.7***	-0.6*	1,998
1715-1719	-0.8***	-0.6***	4,918	-1.1***	-0.9***	3,590
1720-1724	-0.9***	-0.6***	8,327	-1.7***	-1.9***	4,562
1725-1729	-1.9***	-2.0***	9,259	-1.7***	-3.1***	2,341
1730-1734	-2.3***	-3.3***	5,983	-0.9***	-2.4***	1,969
1735-1739	-0.9***	-2.0***	4,982	-0.2	-1.1***	1,674

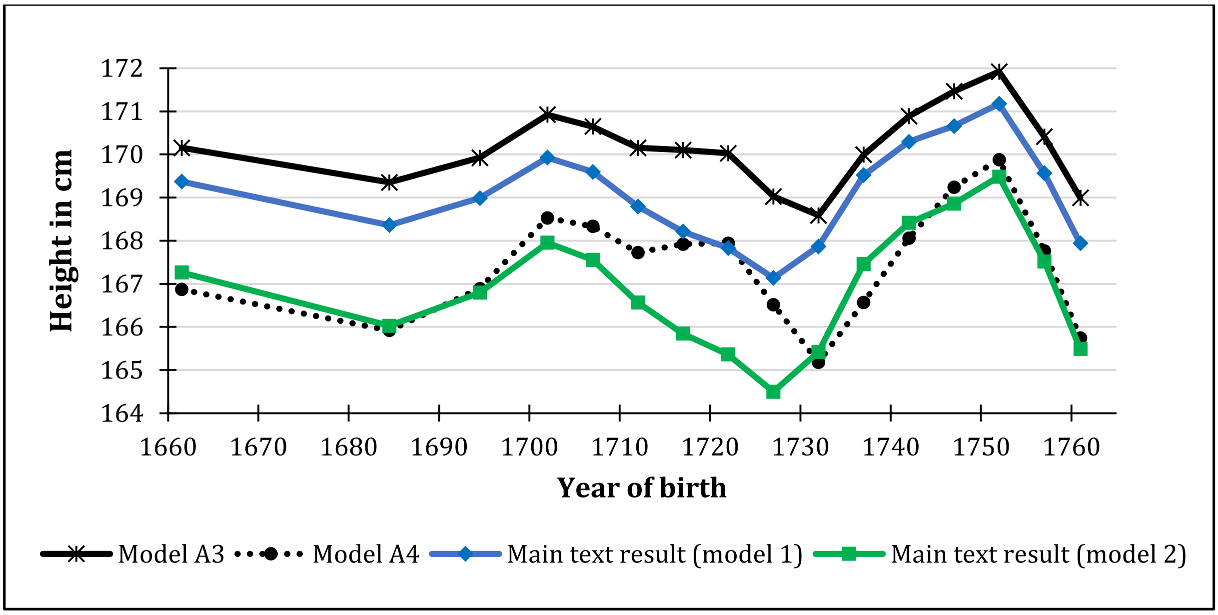
Table continues on the next page

Table A2, continued

Dependent variable: Height in cm	Adults and youth			Adults		
	(A3)	(A4)	N	(A5)	(A6)	N
Birth cohort						
1740-1744	0.0	-0.5*	4,444	1.2***	1.5***	1,404
1745-1749	0.5***	0.7***	4,713	1.7***	2.2***	1,322
1750-1754	1.0***	1.4***	5,783	1.3***	1.7***	1,460
1755-1759	-0.5***	-0.8***	6,702			
1760-1762	-1.9***	-2.8***	2,811			
1755-1762				0.9***	1.1***	1,090
Imperial Circle						
Alsace	Ref.		17,461	Ref.		4,668
Lorraine	1.2***	1.7***	10,961	0.8***	1.2***	2,941
Upper Rhine	1.8***	2.4***	8,633	1.5***	2.1***	2,772
Electoral Rhine	1.7***	2.2***	6,147	1.4***	1.9***	2,554
Burgundia	1.9***	2.4***	5,455	1.6***	2.1***	2,842
Swabia	1.0***	1.4***	4,236	0.7***	1.0***	1,923
Westphalia	1.7***	2.2***	3,557	1.5***	1.9***	1,751
Only HRE	1.6***	2.1***	3,196	1.1***	1.4***	1,699
Austria	0.4**	0.7***	2,295	0.2	0.4	1,124
Bohemia	0.3*	0.5**	2,120	0.1	0.2	1,389
Bavaria	1.0***	1.4***	2,083	0.9***	1.4***	1,190
Franconia	0.8***	1.1***	1,638	0.6**	0.8**	859
Upper Saxony	1.4***	1.9***	1,226	1.1***	1.5***	755
Lower Saxony	2.0***	2.7***	753	1.7***	2.3***	486
Enlistment circumstance						
Enlistment during war	-0.1*	0.8***	31,524	-0.2	0.9***	13,601
Enlistment during peace	Ref.		38,237	Ref.		13,352
Constant	169.4***	166.2***		170.0***	166.6***	
Sigma	5.3***	constrained		5.0***	constrained	
Log-Likelihood	-109,789.4	-110,595.7		-44,959.5	-45,569.4	
N			69,761			26,953

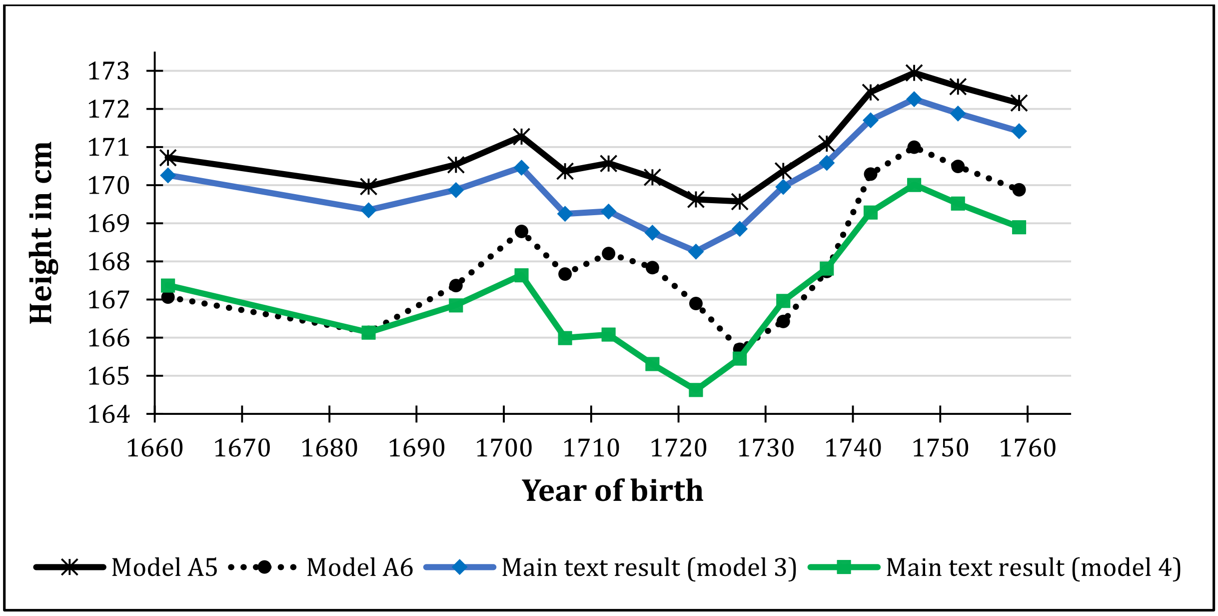
Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In models (A4) and (A6), sigma was constrained to 2.534 Fi (6.86 cm).

Figure A6: Predicted height of recruits born within the HRE: Second alternative truncation point



Sources: See the text and chapter 1, table 3, models 1 and 2. *Notes:* The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

Figure A7: Predicted height of recruits born within the HRE, adults subsample: Second, alternative truncation point



Sources: See the text and chapter 1, table 3, models 3 and 4. *Notes:* The sample used in our calculations consisted of adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

5.3.4. Models with additional control variables

We also investigated whether the inclusion of additional control variables had an effect on coefficient estimates and predicted trends in height. We started by including dummy variables for the regiment of enlistment. These dummies picked up potential regiment-specific heterogeneity associated with the stature of recruits due to differential recruitment. Such heterogeneity may arise due to a variation of the locations of recruitment between regiments, or a heterogeneous “taste” of the recruiting officers for the types of recruits they enlist.

We have established in the preceding section that a truncation point that is constant across Grenadiers does not change the predicted heights compared to the estimates in the main text. Thus, and to ensure comparability of the following estimates with the results in the main text, we used the grenadier-specific truncation points from the main text again. Since we were only interested in the robustness of our predictions with respect to the inclusion of the regimental controls, we do not report the estimated coefficients of the regimental dummy variables in the following table. In predictions, the coefficients of regimental controls were weighted by the respective sample frequencies.

Including controls for the regiment of enlistment did not alter the estimation results substantially compared to the models in the main text (tables 3 and A3). For very young recruits, the age effects were slightly less pronounced than in the main text, but the coefficients were still of a reasonable magnitude. The coefficients of Imperial Circle dummies changed slightly in comparison to the main model results, but the direction of the change was uneven. The most striking difference is that in models A7 and A8, Bohemia was significantly different from the reference category, which was not the case in the other estimations. However, in the subsample where only observations for adults were used, the coefficients for Bohemia are not different from zero (models A9 and A10).

Table A3: Estimation results, regressions with regimental controls included

Dependent variable: Height in cm	Adults and youth			Adults		
	(A7)	(A8)	N	(A9)	(A10)	N
Troop control						
Light troops	-2.1***	-2.7***	1,240	-3.2***	-4.5***	305
Lieut. Colonelle	1.0***	1.3***	4,260	0.7***	0.9***	1,545
Colonelle	4.3***	5.5***	6,421	3.7***	5.1***	2,739
Grenadiers	4.6***	4.0***	2,123	4.0***	3.4***	956
Infantry	Ref.		50,799	Ref.		19,889
Age						
Age 16	-5.6***	-7.4***	2,045			
Age 17	-5.6***	-7.4***	4,380			
Age 18	-4.0***	-5.2***	6,433			
Age 19	-2.6***	-3.4***	6,238			
Age 20	-1.9***	-2.4***	6,485			
Age 21	-0.8***	-1.1***	4,576			
Age 22	-1.1***	-1.4***	5,106			
Age 23	-0.7***	-0.9***	4,146			
Age 24-50	Ref.		25,434			
Birth cohort						
1644-1679	-0.5	-0.6	274	-0.2	-0.3	253
1680-1689	-1.4***	-1.8***	1,027	-1.2***	-1.6***	967
1690-1699	-0.9***	-1.1***	2,646	-0.7***	-1.0***	1,775
1700-1704	Ref.		2,215	Ref.		1,094
1705-1709	-0.1	-0.1	2,324	-1.0***	-1.3***	1,271
1710-1714	-0.6**	-0.7**	2,957	-0.9***	-1.3***	1,785
1715-1719	-1.0***	-1.3***	4,375	-1.5***	-2.1***	3,069
1720-1724	-1.5***	-1.9***	6,988	-2.1***	-3.0***	3,960
1725-1729	-2.2***	-2.9***	7,250	-1.8***	-2.5***	2,341
1730-1734	-2.0***	-2.6***	5,352	-1.2***	-1.6***	1,969
1735-1739	-1.0***	-1.3***	4,982	-0.6**	-0.8**	1,674
1740-1744	-0.6***	-0.7***	4,444	0.4	0.5	1,404
1745-1749	-0.2	-0.3	4,713	1.0***	1.4***	1,322
1750-1754	0.4**	0.5**	5,783	0.7***	1.0***	1,460
1755-1759	-1.1***	-1.4***	6,702			
1760-1763	-2.7***	-3.5***	2,811			
1755-1763				0.3	0.5	1,090
Imperial Circle						
Alsace	Ref.		16,109	Ref.		4,393
Lorraine	0.9***	1.2***	9,837	1.0***	1.4***	2,687
Upper Rhine	1.5***	2.0***	8,344	1.4***	1.9***	2,692
Electoral Rhine	2.0***	2.6***	5,854	1.5***	2.0***	2,455
Burgundia	2.6***	3.3***	5,147	1.8***	2.5***	2,737

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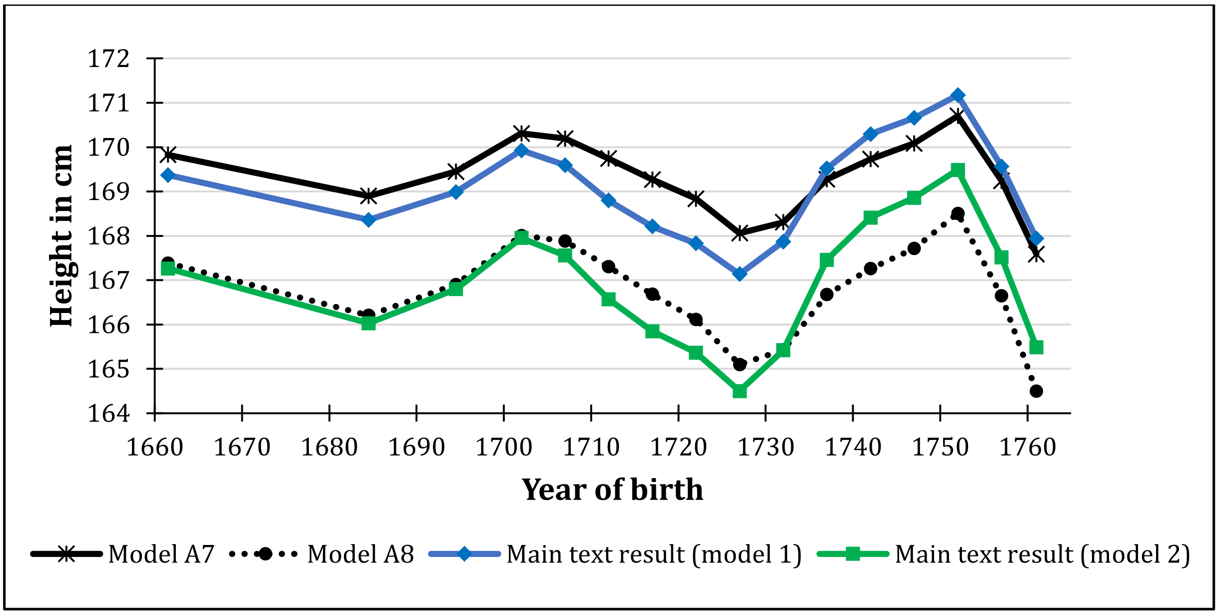
Table A3, continued

Dependent variable: Height in cm	Adults and youth			Adults		
	(A7)	(A8)	N	(A9)	(A10)	N
Imperial Circle						
Swabia	1.4***	1.8***	3,937	0.7***	0.9***	1,808
Westphalia	2.4***	3.1***	3,422	1.8***	2.5***	1,691
Only HRE	2.1***	2.7***	3,040	1.2***	1.7***	1,625
Austria	1.2***	1.5***	2,020	0.4	0.5	1,014
Bohemia	0.5**	0.7**	1,888	0.0	0.0	1,261
Bavaria	1.3***	1.7***	1,856	0.8***	1.1***	1,094
Franconia	1.1***	1.4***	1,518	0.6**	0.8*	805
Upper Saxony	2.2***	2.8***	1,150	1.4***	2.0***	707
Lower Saxony	2.6***	3.3***	721	1.9***	2.7***	465
Enlistment circumstance						
Enlistment during war	-1.1***	-1.4***	26,606	-0.9***	-1.2***	12,082
Enlistment during peace	Ref.		38,237	Ref.		13,352
Regiment controls	N=25	N=25		N=25	N=25	
Constant	168.4***	165.7***		169.3***	165.9***	
Sigma	5.7***	constrained		5.3***	constrained	
Log-Likelihood	-94,297.9	-94,560.6		-39,451.4	-39,697.1	
N			64,843			25,434

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In models (A8) and (A10), Sigma was constrained to 2.534 Fi (6.86cm).

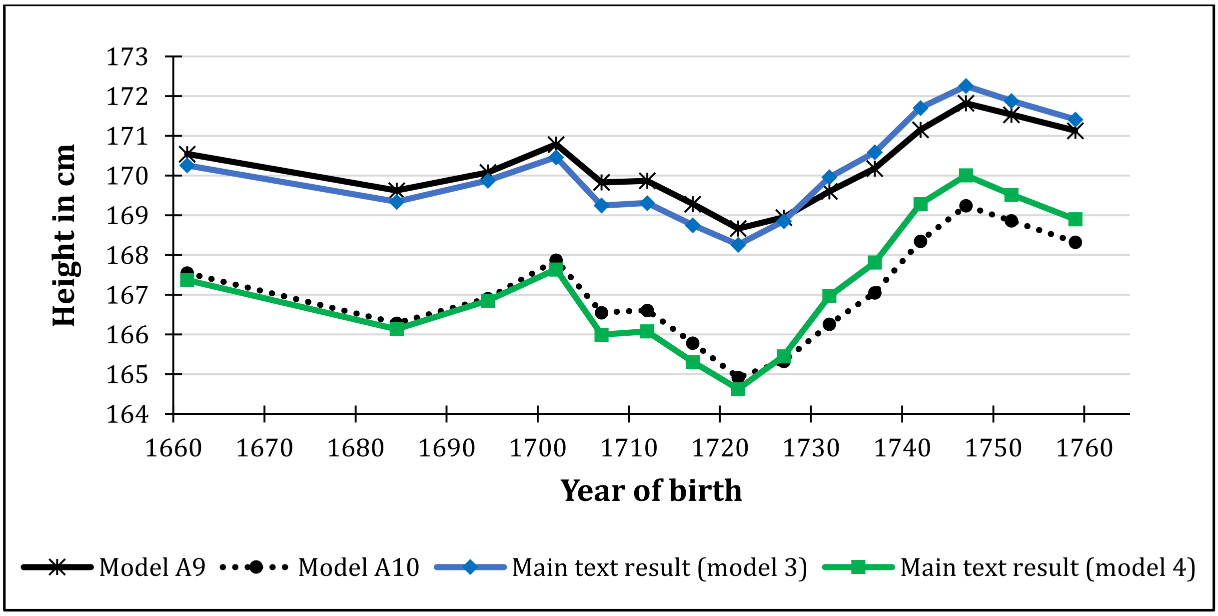
The predicted trends in stature are completely in line with the results in the main text. While there is a slight difference in the level of the predicted heights between the results with and without regimental controls (figure A8), the overall shape of the trends was identical. The difference in the predictions became even smaller when we compared the new predictions to the trends based on the subsamples that contained only adults (figure A9).

Figure A8: Predicted height of recruits born within the HRE: Regressions with regimental controls



Sources: See the text and chapter 1, table 3, models 1 and 2. *Notes*: The sample used in our calculations consisted of youth and adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

Figure A9: Predicted height of recruits born within the HRE, adults subsample: Regressions with regimental controls



Sources: See the text and chapter 1, table 3, models 3 and 4. *Notes*: The sample used in our calculations consisted of adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

Following this, we investigated whether the inclusion of controls for the decade of enlistment had an effect on the predicted heights. Controlling jointly for the year respectively decade of enlistment and the age at enlistment is not feasible in a regression that contains youth (the age controls would need to be included) as well as adults. The obvious reason is that the year of birth is calculated as the difference between the year of enlistment and the age at enlistment. Therefore, controlling for both variables may lead to collinearity problems if for a given year of enlistment, the variation in ages and years of birth is not sufficiently high. If an effect of the year of enlistment on heights existed, as was claimed by Bodenhorn et al. (2015), a selection based on enlistment circumstances would be present and the estimates would be inconsistent. Bodenhorn et al. (2015) supposed that if selection was an issue, the estimated trends might reflect nothing more than selection.

To assess the influence of the timing of recruitment on the estimated trends in the nutritional status, we included dummy variables for the decade of enlistment in the regressions that used only observations of adult recruits, since we did not need to control for age. The growth process was finished for adults, so age should not have an effect on the dependent variable height. Leaving age out of the equation allowed us to include controls for the decade of enlistment instead. Regimental controls were not included in the subsequent models. In predictions, the coefficients of enlistment decade dummies were weighted by the respective sample frequencies.

Including enlistment controls changed the predicted heights substantially for years of birth after 1720. Prior to this, the predictions from models with enlistment controls followed a pattern resembling the one in the main text (table, A4, models A11 and A12, figure A10), albeit at a different level of height. Subsequently, the recovery in predicted heights after 1720 described in the main text was not present when we controlled for the decade of enlistment. The dummy that controls for enlistment during war was of a smaller magnitude but was still significant (table A4, models A11 and A12). Almost completely robust to the inclusion of enlistment controls, on the other hand, were the coefficients of the dummies for Imperial Circles.

Table A4: Estimation results, regressions with enlistment controls included

Dependent variable: Height in cm	Adults		
	(A11)	(A12)	N
Troop category			
Light troops	-3.4***	-4.6***	305
Lieut. Colonelle	0.5**	0.6**	1,545
Colonelle	3.6***	4.8***	2,739
Grenadiers	4.0***	3.5***	956
Infantry	Ref.		19,889
Birth cohort			
1644-1679	0.4	0.6	253
1680-1689	-0.8**	-1.1**	967
1690-1699	-0.8***	-1.0***	1,775
1700-1704	Ref.		1,094
1705-1709	-0.8**	-1.1**	1,271
1710-1714	-0.8**	-1.1**	1,785
1715-1719	-1.4***	-1.9***	3,069
1720-1724	-2.1***	-2.9***	3,960
1725-1729	-2.3***	-3.2***	2,341
1730-1734	-2.1***	-3.0***	1,969
1735-1739	-2.4***	-3.3***	1,674
1740-1744	-1.6***	-2.2***	1,404
1745-1749	-2.1***	-2.9***	1,322
1750-1754	-2.6***	-3.6***	1,460
1755-1762	-3.2***	-4.4***	1,090
Enlistment decade			
1683-1709	-0.2	-0.3	76
1710-1719	-0.8*	-1.0*	942
1720-1729	1.2***	1.6***	1,977
1730-1739	Ref.		1,678
1740-1749	-0.3	-0.5	7,363
1750-1759	0.9***	1.3****	4,919
1760-1769	2.8***	3.8***	3,969
1770-1779	4.6***	6.2***	2,930
1780-1786	4.8***	6.6***	1,580
Imperial Circle			
Alsace	Ref.		4,393
Lorraine	0.9***	1.3***	2,687
Upper Rhine	1.7***	2.3***	2,692
Electoral Rhine	1.5***	2.0***	2,455
Burgundia	1.6***	2.2***	2,737
Swabia	0.6***	0.8***	1,808
Westphalia	1.5***	2.1***	1,691

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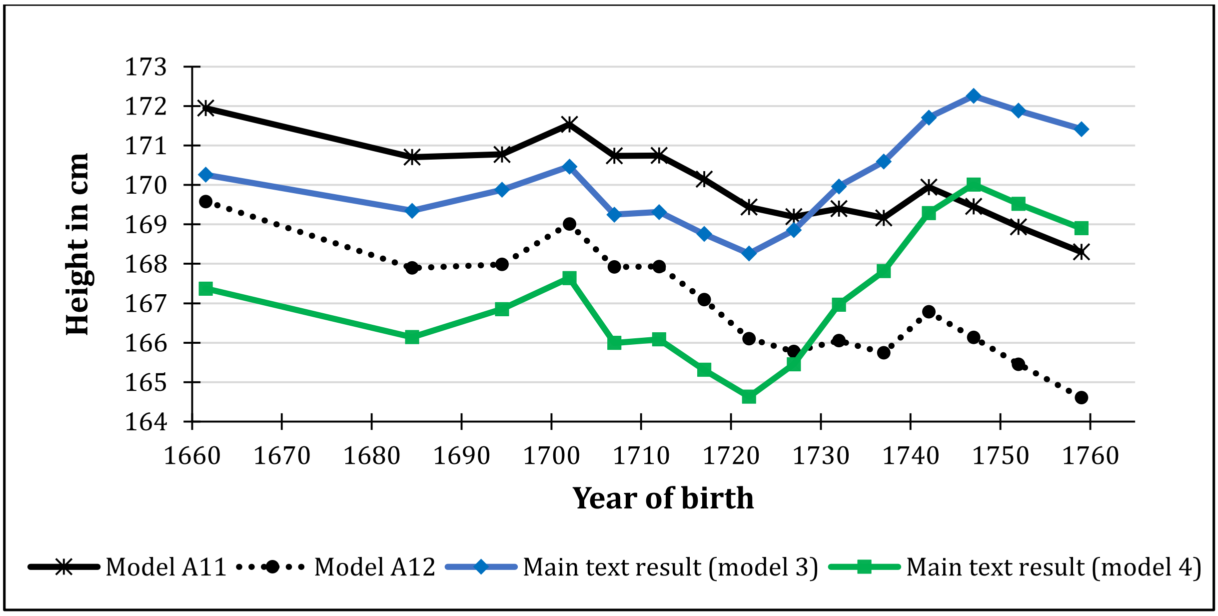
Table A4, continued

Dependent variable: Height in cm	Adults		
	(A11)	(A12)	N
Imperial Circle			
Only HRE	1.1***	1.4***	1,625
Austria	0.3	0.4	1,014
Bohemia	-0.1	-0.1	1,261
Bavaria	0.8***	1.1***	1,094
Franconia	0.5*	0.7*	805
Upper Saxony	1.3***	1.8***	707
Lower Saxony	1.8***	2.5***	465
Enlistment circumstance			
Enlistment during war	-0.3**	-0.4**	12,082
Enlistment during peace	Ref.		13,352
Constant	168.8***	165.4***	-
Sigma	5.3***	constrained	-
Log-Likelihood	-39,563.2	-39,789.4	-
N			25,434

Sources: See the text. *Notes*: *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In model (A12), sigma was constrained to 2.534 Fi (6.86 cm).

Figure A10: Predicted height of recruits born within the HRE, adults subsample: Regressions with enlistment controls



Sources: See the text and chapter 1, table 3, models 3 and 4. *Notes*: The sample used in our calculations consisted of adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

Our results concerning the sign of the enlistment effects were in line with Komlos (2003), where he founds that adult recruits who enlisted in the 1770s and 1780s were taller than recruits who enlisted in the 1730s. Komlos (2003) argued that this could be an indication that during times of recession, taller recruits entered the army. However, he did not include enlistment controls in his regressions[9].

Although the inclusion of controls for the decade of enlistment had a strong influence on our predictions for recruits born after 1720, the models with enlistment controls lack to some extent internal consistency: Bodenhorn et al. (2015) argued that the enlistment decision is driven by economic conditions in the year of enlistment. They maintained that any significant enlistment control variables imply the existence of a selection mechanism. As an indicator of the economic circumstances at the time of enlistment, we used the estimates of real wages calculated by Pfister (2017). These wages provided a measure of opportunity cost of military service that a potential enlistee had to consider. In this respect, the real wage data available is a conservative measure, as Pfister (2017) calculated them for unskilled urban laborers.

We found sizeable effects for the timing of enlistment for all decades except those from 1683 to 1709 and 1740 to 1749. The effects were unsystematic before 1750, as they fluctuate between positive and negative effects. If taller recruits enlisted during economic downturns, as Bodenhorn et al. (2015) argued, real wages should be lower in decades where taller recruits enlisted and higher in decades where shorter recruits enlisted. However, when we studied the trajectories of average real wages per decade relative to the estimated coefficients of decades of enlistment, we found that average real wages and enlistment effects moved in the *same* direction in some decades and in opposite directions in others (figure A11).

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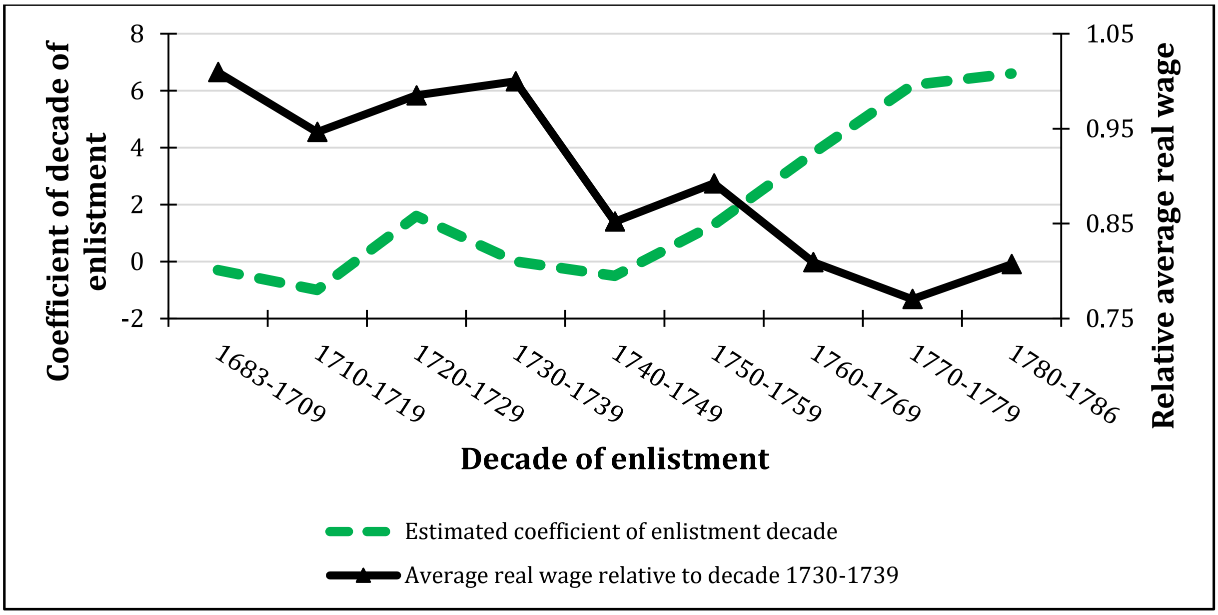
[9] In addition, he stated that an inclusion would not have changed his results substantially (Komlos 2004, p.167).

Figure A11: Enlistment effects and average real wages per decade.



Sources: See the text. Average real wage: Decadal averages based on day real wage from Pfister (2017). Estimated coefficients: Table A4, model A12.

Furthermore, the size of the enlistment effects was not consistent with the relative changes in the real wages. Average real wages were substantially lower in the 1740s than in the 1730s, but this was not accompanied by a steep rise in stature of recruits who enlisted in the 1740s. In fact, those recruits were between 0.5 cm and 0.7 cm *shorter* (but not significantly) than recruits who enlisted in the 1730s. In addition, real wages varied only slightly after the 1760s, but enlistment effects were strongest in this era (figure A11). Given this finding, we drew the conclusion that economic conditions prevalent at the time of enlistment are not reflected in the coefficients of enlistment controls.

A premium was paid for taller soldiers at enlistment, a practice that was formalized in 1763, but presumably[10] also existed before that time. We do not consider the establishment of this practice to be reason for concern and it does not add merit to the inclusion of enlistment controls for a number of reasons: Firstly, it cannot explain the significant effect of enlistment in the 1720s compared to the 1730s. Secondly, we have no reason to assume that the payment was increased or even varied at all after it had been formalized in 1763. Indeed, the estimated enlistment effect was even more pronounced in the 1770s than in the 1760s. As was the case with the trajectory of real wages, this is

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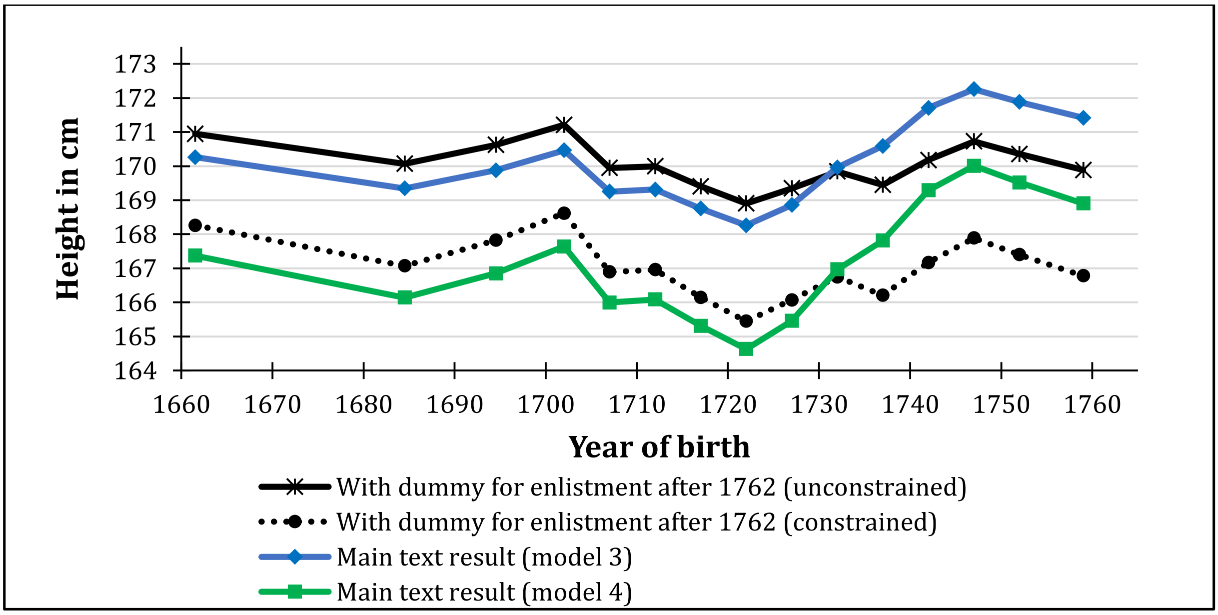
[10] *"L'ordonnance du 1er février 1763, reconnaissant l'usage, fixa un véritable tarif."* (Corvisier 1968, p.83). *"Usage"* refers to the payment of a height premium. Since this practice was recognized in 1763, it must have already existed before; at least we interpreted Corvisier's statement in this way.

not internally consistent. Given this, we are still confident that selection[11] was not a driving force behind our results. Regressions that included a dummy variable for years of enlistment after 1763 yielded predictions that were –except for a shift in the level of heights – identical to the regressions without enlistment controls until the middle of the 1730s. In the following quinquennium of birth, heights declined, whereas they already began to recover at this time in regressions without enlistment controls. Heights subsequently increased again, but the degree of the increase was smaller compared to the results in the main text. In particular, the reversals in the directions of the trends we estimated over the whole epoch were identical in all regressions (figure A12). Thus, we do not consider it necessary to include a dummy variable for enlistment after 1762 in the regressions. What's more, this decision allowed us to retain the observations for youth in our analysis, and the information contained in these observations enabled us to base our conclusions on a broader evidential basis.

Figure A12: Predicted height of recruits born within the HRE, adults subsample: Comparison of regressions with and without a dummy for enlistment after 1763.



Sources: See the text and chapter 1, table 3, models 3 and 4. *Notes*: The sample used in our calculations consisted of adults. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

A'Hearn and Komlos (2016) also refuted the claims made by Bodenhorn et al. (2015) with respect to the "Antebellum Puzzle" in the United States. In addition, other studies of trends in stature usually did not include controls for the decade of enlistment: For example, Koch

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[11] Corvisier (1968) made his statement in the context of *cheating* in terms of stature during enlistment. So, this "premium" has a random component to it.

(2012), Heyberger (2007) or Cinnirella (2008). We therefore decided to follow the approaches established in the literature. No regression in the main text controls for the decade of enlistment.

5.3.5. Supplementary regressions for the Eastern region of the Empire

Because the trend we estimated for the Eastern part of the Empire implied a very strong growth in heights starting after the 1720s, we also estimated the trend in a subsample that contained only adults to ensure our findings were robust. These additional regressions yielded estimates that were qualitatively identical[12] to the results found in the main text (table A5, figure A13). The same was true if the definition of adults was altered to include recruits aged 22 or older (figure A13).

Table A5: Estimation results, East subsample

Dependent variable: Height in cm	Adults		
	(A13)	(A14)	N
Troop category			
Lieut. Colonelle	0.6	0.9	86
Colonelle	3.4***	4.8***	195
Infantry	Ref.		1,101
Birth cohort			
1651-1689	1.3*	2.0*	145
1690-1699	1.9***	2.8***	176
1700-1709	1.7**	2.5**	153
1710-1719	0.7	1.1	242
1720-1729	Ref.		294
1730-1739	1.8**	2.6**	148
1740-1749	4.0***	5.7***	100
1750-1762	3.9***	5.5***	124
Territory			
Hohenzollern possessions	Ref.		277
Unknown	-0.3	-0.4	239
Electorate of Saxony	-1.6**	-2.3**	224
Electorate of Hannover	1.0	1.4	171
Only Lower Saxony	-1.0	-1.4	160
Ernestine Territories	-1.0	-1.5	117
Free or Imperial Cities	0.2	0.3	107
Only Upper Saxony	-0.8	-1.1	87

Table continues on the next page

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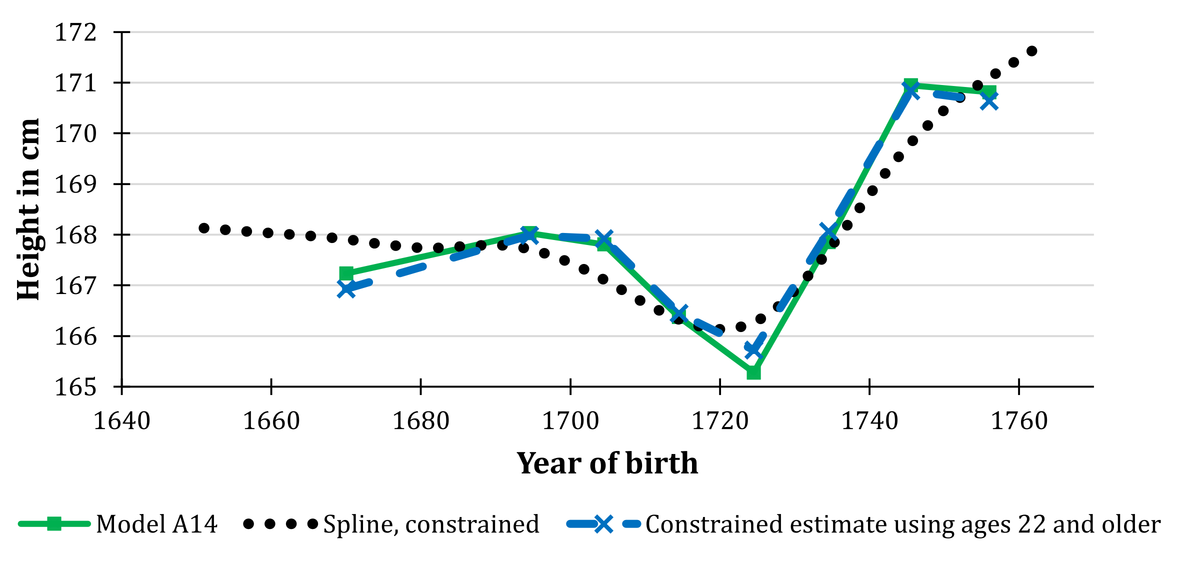
[12] An increase in heights was also estimated when we estimated a regression using only years of birth from 1740 on and only included age controls (not shown).

Table A5, continued

Dependent variable: Height in cm	Adults		
	(A13)	(A14)	N
Enlistment circumstance			
Enlistment during war	-0.9**	-1.3**	672
Enlistment during peace	Ref.		710
Constant	169.6***	165.8***	
Sigma	5.1***	constrained	
Log-Likelihood	-2,204.7	-2,225.5	
N			1,382

Sources: See the text. *Notes*: *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In model (A14), Sigma was constrained to 2.534 Fi (6.86 cm).

Figure A13: Predicted height of recruits born within the Eastern region of the HRE, adults subsample: Different models



Sources: See the text and model A14. *Notes*: The sample used in our calculations consisted of adults unless otherwise noted. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

5.4. Calculations of the population density of Imperial Circles

Hartmann (1995) estimated total populations[13] of each Imperial Circle in 1795. We used these population figures without modification for the following circles: Electoral and

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[13] Note that Hartmann (1995) did not take the territories of the Imperial Knights into account.

Upper[14] Rhine, Lower Saxony, Bavaria, Westphalia, Burgundy, Swabia and Franconia. For Alsace and Lorraine, we used population figures for the decade 1778 to 1787 reported in (Dupâquier[15] 1988). Because our definition of the Upper Saxon Circle also contains Lusatia, we added up the population figures in Hartmann (1995) for the Upper Saxon Circle and Lusatia[16]. For Bohemia, Moravia and Silesia, Hartmann (1995) calculated a range of estimates. We used the highest values available[17]. The value for Austria that Hartmann reported was advantageous since it contained Anterior Austria, while the figures that Bardet and Dupâquier (1998) calculated for Austria contained Salzburg, which was part of the Bavarian Circle. Consequently, we again used Hartmann's estimates[18].

The surface areas of the Imperial Circles were calculated[19] based on a shapefile we created for figures 7 and 9 in the main text and for figure A1 in this appendix.

Our primary estimate of the population density in Upper Saxony was based on the previously described extended definition of this circle. We only had crude population estimates[20] for the extended parts of the circle at our disposal. The population density we calculated for the extended circle was 30.5 inhabitants per km^2. This may understate the

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[14] Formally, Alsace and Lorraine were part of the Upper Rhenish circle. Hartmann (1995) did not mention them in his text, so we assumed that they were excluded from the population figures he calculated. This would be sensible because these tow territories were already integrated into France in 1795.

[15] Dupâquier (1988, p.76, tableau 1 : „Population des Intendances au début et à la fin du XVIIIe siècle"). We used the figures pertaining to the "Généralités" of Strasbourg and Nancy, which should approximate the Alsace and the Duchy of Lorraine.

[16] The calculation of the surface area of Upper Saxony also took this into account.

[17] The values Hartmann (1995) calculated were consistent with other sources. Hartmann's largest estimate of the Bohemian population was 2.9 million, Bardet and Dupâquier (1998) estimated 2.56 million for 1780. For Moravia, the corresponding vales were 1.4 million and 1.175 million. For Silesia, Hartmann estimated 1.776 million people, and Bardet and Dupâquier (1998) estimated 1.8 million people, but this time for 1794.

[18] The difference in the estimated population between Hartmann's figure for 1795 (2.94 million) to Bardet and Dupâquier's figure for 1780 (2.796 million) does in our opinion not imply an inconsistency, but could very well be the consequence of the accelerated population growth and the different times of measurement.

[19] A command in the software QGIS, version 2.14 was used. We did not write, compile or program any part of the software nor the command to calculate the surface area.

[20] To the total population of actual Upper Saxony, we added an estimate of the population in Eastern Prussia in 1800 from Bardet and Dupâquier (1998), as well as a crude estimate for the population in Western Prussia. This crude estimate was based on adding up the population of the cities Danzig (Gdansk), Kulm (Chelmno), Marienwerder (Kwidzyn), Bromberg (Bydgoszcz), Marienburg (Malbork) and Graudenz (Grudziadz) in 1800 (all values from Bairoch et al. 1988). This sum of city populations was then divided by the average rate of urbanization in Germany of 9.4% in 1800 (Bairoch et al. 1988). Using this population figure, the resulting population density for Western Prussia alone would be 18.2 inhabitants per km^2. This is close to the population density that Bardet and Dupâquier (1997, we read off the values from: p..569, figure 79, so they should be considered approximations.) report for western Prussia in 1772. The density should be between 20 and 30 inhabitants per km^2. Unfortunately, Bardet and Dupâquier (1997) did not report total population for Western Prussia, because otherwise we would have used this figure instead of our approximations.

true population density. Accordingly, we also calculated an alternative population density of Upper Saxony, but this time we **only** used the surface area of the *actual* upper Saxon Circle, as described in figure A1, and **only** the population figures of the *actual* upper Saxon Circle in the calculation[21]. The resulting population density was higher, at 36.5 inhabitants per km^2. Note that we were conservative in the main text, since we depicted both population densities. The combination of the estimated height in Upper Saxony and the alternative population density fitted even better into the negative relationship described in the main text in chapter 2 than does the estimate based on the extended definition of the circle. We hypothesize that this is the result of the few observations from the extended parts of the circle.

We had only a low amount of supplementary information to verify our calculations of the population densities or of the surface area of each Imperial Circles. For Alsace and Lorraine, Dupâquier (1988) reported population densities as well as their corresponding surface areas. When we used his estimates of the surface areas, instead of ours, the effect on the population density is minimal, it decreases by 2.3 inhabitants per km^2 for Lorraine respectively 1.2 inhabitants per km^2 for Alsace. This had practically no effect on the relationship between heights and population density we documented in the main text. Our estimated population density in Alsace is also well-matched to values in (Bardet and Dupâquier 1998): For Alsace in 1806, they estimated a density of 66 inhabitants[22] per km^2, and we estimated a density of 59.6 inhabitants per km^2.

5.5. Regression results using the estimated height of youth as the dependent variable

It is conceivable that effect of the explanatory variables used in the main text regressions may be stronger for recruits whose growth process was not finished at the time of measurement. Therefore, we repeated the regressions in tables 11 to 13, with the estimated stature of youth as the dependent variable: We first estimated regressions analogous to models 1 and 2 in the main text, using the same explanatory variables[23], but the sample used in the estimation was restricted to recruits aged 16 to 23. We also

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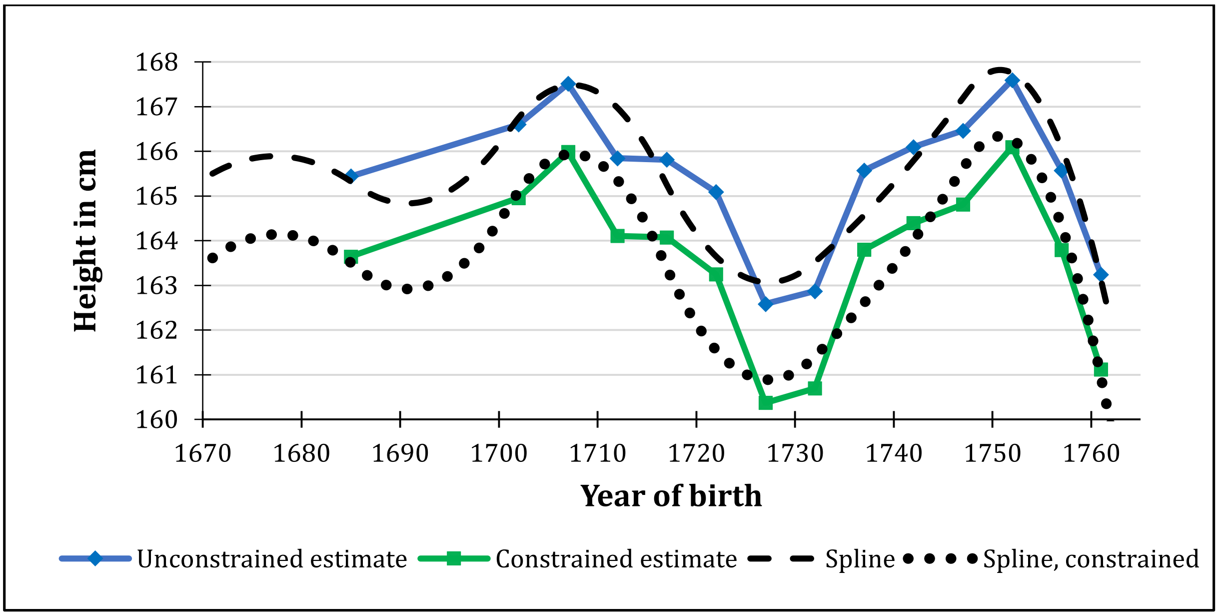
[21] We considered Lusatia as part of the actual Upper Saxon Circle. Consequently, we added up the population figures in Hartmann (1995) for the Upper Saxon Circle and Lusatia to calculate the population of the actual circle. The surface area of the circle also accounted for the inclusion of Lusatia.

[22] (Bardet and Dupâquier 1998, p.293, figure 43).

[23] Due to the low number of observations, Upper and Lower Saxony were combined.

estimated unconstrained and constrained spline regressions. The estimated heights for youth follow a qualitatively similar trend as for the adults, but the variation of stature is higher (figure A14). Spline regressions were well-matched[24] to the dummy variable results. In all predictions, explanatory variables (including the age controls) were weighted by their sample proportions, so that the predicted heights represented an average young soldier.

Figure A14: Estimated height of youth recruits based on the youth sample



Sources: See the text. *Notes*: The sample used in our calculations consists of youth. Point estimates of birth cohort dummy coefficients were plotted in the middle of the respective cohort.

We also estimated regressions analogous to those in the main text where we examined the determinants of height, now using the estimated height of youth as the dependent variable. The signs of the estimated coefficients were identical to those found in the main text for rye prices and in most regressions also for rainfall[25], but not for winter temperatures. The effects of real wages were in some specifications also different from the main text results (tables A6 and A7). Population had a significant and positive effect even in the first time period studied (tables A6 and A7). The magnitudes of the effects differed compared to the main text results. In particular, the effect of rye prices was more pronounced, as was expected.

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[24] For the spline estimates, the smoothing parameter had to be selected manually, as the automatically selected smoothing parameter yielded a smooth that fluctuated too much to be compatible with variations typically found in stature.

[25] But the coefficient of rainfall was not significant.

Table A6: Determinants of height: Regression results for years 1671 to 1710

Dependent variable: Predicted height of youth in cm (constrained spline regression depicted in figure A14)

	(A15)	(A16)	(A17)	(A18)
Average rye price during the first 16 years of life	-27.8***	-24.8***	-25.1***	-31.5***
Average winter temperature during the first 16 years of life			-0.6	-0.3
Average rainfall during the first 16 years of life		-0.01	-0.03	0.02
Average total population during the first 16 years of life				0.5***
Constant	173.7***	174.7***	177.3***	163.6***
N	40			
Adjusted-R^2	0.6	0.6	0.6	0.8
F	62.0	30.4	21.1	67.7

Sources: See the text. *Notes*: *: $p<0.1$, **: $p<0.05$, ***: $p<0.01$. Significances of the coefficients were identical when standard errors were bootstrapped (1000 replications). The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

Table A7: Determinants of height: Regression results for years 1665 to 1710

Dependent variable: Predicted height of youth in cm (constrained spline regression depicted in figure A14)

	(A19)	(A20)	(A21)	(A22)	(A23)
Average real wage during the first 16 years of life	-0.5	-0.2	-0.1	7.6***	6.8***
Average winter temperature during the first 16 years of life			-0.5	-0.1	
Average rainfall during the first 16 years of life		-0.06***	-0.08***	0.02	
Average total population during the first 16 years of life				1.8***	1.6***
Constant	166.3***	173.8***	175.7***	95.8***	105.3***
N	40				
Adjusted-R^2	-0.0	0.3	0.3	0.9	0.9
F	0.9	12.0	8.2	127.0	222.9

Sources: See the text. *Notes*: *: $p<0.1$, **: $p<0.05$, ***: $p<0.01$. Significances of the coefficients were identical when standard errors were bootstrapped (1000 replications). The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

In the second time period, the magnitude of the effects did not vary uniformly compared to the main text results (table A7): Total population and rainfall had smaller coefficients than in the main text, but the coefficients of rye price and real wage were at a similar level in comparison to the main text. Winter temperature had a larger negative effect now. The signs of the coefficients were perfectly compatible[26] with the main text results.

Table A8: Determinants of height: Regression results for years 1711 to 1762

Dependent variable: Predicted height of youth in cm (constrained spline regression depicted in figure A14)		
	(A24)	(A25)
Average rye price during the first 16 years of life	-25.2***	
Average winter temperature during the first 16 years of life	-3.3***	-3.9***
Average rainfall during the first 16 years of life	-0.04***	-0.05***
Average total population during the first 16 years of life	0.9***	1.3**
Average real wage during the first 16 years of life		4.7**
Constant	156.2***	123.4***
N	52	
Adjusted-R^2	0.6	0.5
F	40.0	29.8

Sources: See the text. *Notes*: *: p<0.1, **: p<0.05, ***: p<0.01. Significances of the coefficients were identical when standard errors were bootstrapped (1000 replications). The adjusted R^2 reported was always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

When an interaction term for population was added to the models in table A8, the primary difference to the main text results was that in a model that contains the real wage (model A27), population has no effect before 1755. In the main text, the influence of population was actually positive and significant. Furthermore, the sign of the real wage was negative in table A9 (albeit insignificant), while the effect was positive, small and insignificant in the main text (table 14).

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[26] Note that contrary to the main text results, once temperature was included as a control variable, the coefficients of rye prices had the expected signs even if population was left out, but these coefficients were insignificant in specifications without controls for population (results not shown).

Table A9: Regression results for years 1711 to 1762 including interaction terms

Dependent variable: Predicted height of youth in cm (constrained spline regression depicted in figure A14)		
	(A26)	(A27)
Average rye price during the first 16 years of life	-7.5	
Average winter temperature during the first 16 years of life	-3.7***	-3.7***
Average rainfall during the first 16 years of life	0.01	0.01
Average total population during the first 16 years of life	0.8***	0.6
Average total population during the first 16 years of life *years after 1754	-0.1***	-0.2***
Average real wage during the first 16 years of life		-0.3
Constant	147.0***	149.1***
N	52	
Adjusted-R^2	0.7	0.7
F	41.9	35.7

Sources: see the text. Notes: *: p<0.1, **: p<0.05, ***: p<0.01. Significances of the coefficients were identical when standard errors were bootstrapped (1000 replications). The adjusted R^2 reported is always obtained from the regressions with bootstrapped standard errors. Results were rounded to one, respectively two decimal places.

This suggests that the results using only youth heights as the dependent variable corroborate to a large extent the conclusions drawn in the main text. We hypothesize that the differences between the results for adults and youth could be the results of the unfinished growth process for youth at the time of measurement.

Following this, we also estimated additional regressions similar to models 1 and 2 in chapter 1 using observations for adults and youth, but we added additional control variables to the models. The models reported below always contained the following control variables that were also used in the main text: Controls for special troops, Imperial Circles, ages until 23, dummies for decades of birth and a dummy for enlistment during war. For the sake of readability of the tables, the estimated coefficients of these variables are not reported.

The effect of the rye prices at birth had the expected negative sign and was significant. This effect was robust to the inclusion of other control variables. Yet, the variables that represent the averages after birth were not significant for rye price, but had the correct sign. Winter temperature or rainfall at birth had no effect, but the averages did. The effect of winter temperature was contrary to expectations (table A10). By using real wages as the primary explanatory variable, we obtained qualitatively identical results (table A11).

Table A10: Truncated regression including additional control variables.

Dependent variable: Height in cm	Adults and youth													
	(A28)	(A29)	(A30)	(A31)	(A32)	(A33)	(A34)	(A35)	(A36)	(A37)	(A38)	(A39)	(A40)	(A41)
Rye price at birth	-1.5**	-1.8**	-1.6***	-2.0***	-1.5**	-1.8**	-1.6***	2.0***	-1.4**	-1.8**	-1.4**	-1.7**	-1.3**	-1.6**
Average rye price during 15 years after birth			-5.1	-6.3			-5.3	-6.5	-4.9	-6.1			-3.3	-4.0
Winter temperature at birth					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average winter temperature during 15 years after birth									-0.7***	-0.9***			-0.7***	-0.9***
Rainfall at birth											0.0	0.0	0.0	0.0
Average rainfall during 15 years after birth													-0.02**	-0.03**
Sigma	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.

Sources: See the text. *Notes*: *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one, respectively two decimal places. In models (A29), (A31), (A33), (A35), (A37), (A39) and (A41), Sigma was constrained to 2.534 Fi (6.86 cm). All models included controls for special troops, Imperial Circles, ages until 23, dummies for decades of birth and a dummy for enlistment during war.

Table A11: Truncated regression including additional control variables.

Dependent variable: Height in cm	Adults and youth													
	(A42)	(A43)	(A44)	(A45)	(A46)	(A47)	(A48)	(A49)	(A50)	(A51)	(A52)	(A53)	(A54)	(A55)
Real wage at birth	0.8***	1.0***	0.8***	1.0***	0.8***	1.0***	0.8***	1.0***	0.7***	0.9***	0.8***	1.0***	0.7***	0.8***
Average real wage during 15 years after birth			1.0	1.2			1.0	1.3	1.0	1.2			0.9	1.1
Winter temperature at birth					0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average winter temperature during 15 years after birth									-0.6***	-0.7***			-0.6***	-0.8***
Rainfall at birth											0.0	0.0	0.0	0.0
Average rainfall during 15 years after birth													-0.03**	-0.03**
Sigma	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.	5.8***	constr.

Sources: See the text. *Notes:* *: p<0.1, **: p<0.05, ***: p<0.01. Heteroscedasticity-robust standard errors were used. Sigma denotes the estimated standard deviation of the dependent variable. Estimations were conducted in French inch and converted into cm for the table. Results were rounded to one decimal place. In models (43), (A45), (A47), (A49), (A51), (A53) and (A55), Sigma was constrained to 2.534 Fi (6.86cm). All models included controls for special troops, Imperial Circles, ages until 23, dummies for decades of birth and a dummy for enlistment during war.

Main references consulted and shapefiles used to construct the Imperial Circles

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[432] All other citations used in this appendix refer to the main text appendix.

und vorbereitetet von Edmund E. Stengel, bearbeitet von Friedrich Uhlhorn; Hessisches Landesamt für geschichtliche Landeskunde; Marburg/Lahn

Robert de Vaugondy, Gilles, Robert de Vaugondy, Didier and Boudet, Antoine. 1757. „Atlas Universel: Avec Privilège Du Roy“ chez les auteurs, Boudet, Paris.

From this Atlas, the following maps are used to define the territorial division of the Spanish/Austrian Netherlands.

Sr.Robert de Vaugondy. 1751. „Pays-Bas catholiques“

Sr.Robert de Vaugondy. 1752. „Partie meridion. du Duché de Brabant - Le Comté de Namur“

Sr.Robert de Vaugondy, fils. 1752. „“Comté de Flandre“

Sr.Robert de Vaugondy, fils. 1752. „Partie septentrionale du Duché de Brabant“

Sr.Robert. de Vaugondy. 1753. „Carte du duche de Luxembourg“

Sr.Robert. 1753. „Les Provinces-Unies des Pays-Bas“

Sr.Robert. 1754. „Comtés de Hainaut et de Cambresis“

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Shapefiles

All shapefiles have been subject to modifications by us, in particular, but not exclusively, deletions, re-projections and changes in the coordinate system were carried out.

“Communes, 2013, administrative units, dataset” © Euro Geographics for the administrative boundaries, European Commission, Eurostat (ESTAT), GISCO. Downloaded from: http://ec.europa.eu/eurostat/cache/GISCO/geodatafiles/COMM-01M-2013-SH.zip last access: 05.04.2016

“Countries, 2013, administrative units, dataset” © Euro Geographics for the administrative boundaries European Commission, Eurostat (ESTAT), GISCO. Downloaded from: http://ec.europa.eu/eurostat/cache/GISCO/geodatafiles/CNTR-01M-2013-SH.zip last access:05.04.2016

„Generalisierte Gemeindegrenzen der Schweiz“ © Bundesamt für Statistik (BFS), GEOSTAT 2014. Downloaded from: http://www.bfs.admin.ch/bfs/portal/de/index/dienstleistungen/geostat/datenbeschreibung/generalisierte_gemeindegrenzen.Document.166578.zip last access: 01.05.2014.

"GEOFLA® Communes 2011", © INSEE/ IGN-F 2014. Downloaded from: https://wxs-telechargement.ign.fr/oikr5jryiph0iwhw36053ptm/telechargement/inspire/GEOFLA_THEME-COMMUNE_2011_GEOFLA_1-1_SHP_LAMB93_FR-ED111/file/GEOFLA_1-1_SHP_LAMB93_FR-ED111.7z last access: 01.05.2014.

"Provinci 1991", © ISTAT 2014. Downloaded from: http://www.istat.it/storage/basi_territoriali_2013/LimitiAmministrativi/Limiti1991/Prov1991_WGS84.zip last access: 01.05.2014.

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The following shapefiles were only obtainable as point data and consequently converted:

For visualizations and geocoding, polygons were created out of the points using a Voronoi-polygon algorithm in QGIS 2.2-2.14. We did not write any parts of this algorithm nor the program. Note that the polygons created this way do not represent administrative borders of communities.

Belgium: "Places 2016" © OpenStreetMap contributors, Open Database 1.0 License, downloaded from: http://download.geofabrik.de/europe/belgium-latest.shp.zip last access: 05.04.2016. We cleaned the file of any non-settlements and isolated dwellings.

Luxembourg: "Places 2016" © OpenStreetMap contributors, Geofabrik. Open Database 1.0 License, downloaded from: http://download.geofabrik.de/europe/luxembourg-latest.shp.zip last access: 05.04.2016. We cleaned the file of any non-settlements and isolated dwellings.

Netherlands: "Places 2016" © OpenStreetMap contributors, Geofabrik. Open Database 1.0 License, downloaded from: http://download.geofabrik.de/europe/netherlands-latest.shp.zip last access: 05.04.2016. We cleaned the file of any non-settlements and isolated dwellings.

6. Data appendix: Foreigners in the French Army - A guide to the dataset and its construction

This appendix describes the necessary steps we carried out to construct a dataset based on digitized[1] French muster rolls stored in the *"Archives de la guerre".* The dataset is limited to infantry regiments[2], with a focus on "foreign" regiments. since this data has not been studied in detail so far. The dataset contains information for a time period where individual level data is scarce and for large number of regions in Europe. However, the dataset as such is not without its problems and peculiarities that need to be addressed before researchers can work with the dataset.

This appendix has a two-fold purpose: The first is to document the coding of the raw data. Second, it supposed to serve as a self-contained research guide in the spirit of Corvisier's (1968 and 1970) research guide to the *"Controles des troupes"*, but with more emphasis on the usefulness of the data for a statistical analysis. A detailed summary of the assumptions we made, in particular with respect to the geocoding process used to determine the recruits' localities of birth is included, as well as a discussion of the truncation of the variable "height".

Most of the aspects of the data described in the following sections have already been discussed by Corvisier (1968 and 1970). It should be noted that we do not know whether the statements made by Corvisier generalize to the "foreign" troops, but in lack of a source that deals with these foreign regiments specifically, Corvisier's works are our primary source. In terms of the organization of regiments, there is evidence that mercenary troops were organized similar to "native" French troops, since Lynn (1997, p.333) states: *"[...] the mercenary regiments copied the forms of the new state regiments, not the other way around."* We hope that this statement generalizes to "foreign" regiments also in terms of the organization of records.

Since this is **not** the first text to discuss these data, overlaps with Corvisier's (1968 and 1790) works are unavoidable[3]. Yet, we specifically address the data problems found in our *sample* of the muster rolls, so contrary to Corvisier, we do not discuss the *"Controles*

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[1] We thank John Komlos for granting us the opportunity to work with his microfilm copies of the muster rolls. Financial support of the DGF in acquiring and digitizing the muster rolls is greatly appreciated.

[2] Archival designations starting with *"1Yc"*. See (Corvisier 1970) for details.

[3] We try to provide the references to Corvisier's works as often as possible, but in case of doubt credit for the discovery of a special aspect of the data should be given to Corvisier. Readers interested in a more detailed description of the records than we can provide here, are encourage to refer to Corvisier's work.

des troupes" in a general manner, but with respect to the muster rolls we digitized. A short description of the foreign regiments is also provided to take the special character of these regiments into account.

This appendix is organized as follows: Section 1 describes the overall structure of the data. Section 2 gives an introduction to the individual information that has been recorded and digitized, as well the recoding processes used to harmonize the information. Section 3 asses the issue of duplicates. Section 4 briefly discusses aspects of selectivity of the data. Section 5 concludes.

6.1. Data structure

A total of 159,239 observations were digitized[4] from hand-written muster rolls[5]. The overall organization of the muster rolls is as follows: The crudest information is the name of a regiment a recruit enlisted in. Regiments are subdivided into battalions, contained in the muster rolls in one or more registers, and those are subdivided into companies. On the company-level, the muster rolls are based on a printed template. The individual-specific information about the recruits was then inserted in writing. We first present the steps that were carried out to harmonize the overall data structure.

6.1.1. Definition of a Regiment

Some regiments present in our data were re-named, disbanded or combined with other regiments. Thus, regiments are not defined based solely on their names provided in the original documents, but are defined using the information about changes of names provided in (Corvisier 1970).

Regiments that were at one point in time merged or incorporated into another regiment are treated as separate regiments in the dataset (table DA1).

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[4] We thank Cathrin Mohr, Eni Kumbaro, Alexander Sel, Isabell Flex, Stefan Stenzel, Michaela Binder, Erich Foltyn, Felix and Jonas Block an unknown student assistant for digitizing the original dataset. To account for the special structure of the dataset, we double-checked every digitized observation.

[5] See references for a list of the archival designations.

Table DA1: Incorporated regiments

Regiment	Signature	Incorporation	Enrollment dates	N
La Dauphine	1 Yc296	Royal Bavière in 1760	1747-1754	3,360
Royal Ecossais	1 Yc871	Bulkeley in 1762	1744-1766	3,902
Saint-Germain	1 Yc935 1 Yc936	Nassau in 1760	1747-1756	2,867
Albanie	1 Yc7	Royal Ecossais in 1749	1748	83
Lowendal	1 Yc523	1st battalion: Anhalt in 1760 2nd battailon: La Marck in 1760	1743-1750	1,227
Rooth	1 Yc784 1 Yc785 1 Yc786	1775 into Legion Corse	1690-1764	3,715
Olonne	1 Yc638	Rochefort	1689-1722	1,047

Sources: See the text and Corvisier (1970).

A special case are the observations where the name of the regiment is given as "Lorraine". These recruits can be enlisted in three different regiments all called "Lorraine" at one point in time (table DA2). We treat all three as separate entities[6].

Table DA2: Lorraine regiments

Regiment	Signature	Comment	N
Lorraine, crated in 1684	1 Yc510 1 Yc511 1 Yc512 1 Yc516 (in parts)	Later incorporated into the regiment Aunis[7]	3,816
Royal Lorraine	1 Yc516 (in parts)	Formed in 1744 with the militia of Lorraine.	1,168
Gardes Lorraines	1 Yc517 1 Yc520	Former regiment Carignan	6,381

Sources: See the text and Corvisier (1970).

The other regiments are not subject to modifications and are used "as is".

6.1.2. Definition of a Company

Defining companies correctly is important to distinguish ordinary companies from special troops. It cannot be ruled out that those special companies had different requirements with respect to the individual characteristics of the recruits, for example a minimum height requirement: Komlos (2003, p.166 and footnote 16) found substantial differences in the unadjusted average height of soldiers enlisted in special companies compared to ordinary companies. Since the names of companies were frequently changed, we use the

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[6] The assignment to one of the specific "Lorraine" regiments is based on the signatures and (Corvisier 1970).

[7] Our dataset does not contain soldiers from the regiment "Aunis".

information in (Corvisier 1970) to distinguish companies. We distinguish between *Grenadiers, Colonelle*[8]*, Lieut. Colonelle, Chasseurs* and *ordinary troops"*[9].

6.2. Information content

In this section, we describe the individual-specific information found in the muster rolls[10]. We start with the quality of the basic information[11] about a recruit. By "basic information" we mean a recruit's date of enlistment, his age, height and the geographical information about the locality of birth. An overview over supplementary[12] information is provided afterwards, as this additional information is available with a varying incidence.

6.2.1. Year of enlistment

The date of enlistment in the muster rolls was digitized as "year only[13]", even if the muster rolls also contain the month or even day of enlistment. Observations with a year of enlistment smaller than the year of creation[14] of the regiment are discarded (N=30), with some exemptions:

- The Irish[15] regiment "Dillon" was passed to French service in 1690 (Corvisier 1970, p.98), and the date of creation is not known to us. We drop recruits that enlisted before 1685 (N=8).
- The German regiments "Bouillon" and "Royal Deux-Ponts" were both officially created in 1757 (Corvisier 1970, p.606, p609). Assuming that some preliminary recruiting took place, we remove recruits born before 1756 (N=87) from the dataset. The reason

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[8] This category also contains recruits enlisted in companies designated "Mestre de camp" since: *"When a colonel general held office, regimental commanders below him officially bore the title of mestre de camp, rather than colonel"* (Lynn, 1997 p.266). Also, this category contains 490 recruits enlisted in companies encompassing the title "commandant" and 64 observations assigned to the company "Etat Mayor". After 1749, the name "Colonelle" was passed always to the company with the oldest captain (Corvisier, 1970, p.4). For details on the naming of the "Colonelle" company, see (Corvisier 1968, p.117-118 and 1970, p.4). A case not found in Corviser's (1968) discussion are designations "chef de battalion". We keep those observations in the "Infantry" category (N=1,789)

[9] This category also contains 151 observations enlisted in an "auxiliary company". This "auxiliary company" is exclusive to the regiment "Royal Deux-Ponts" (signature 1 Yc869) and contains recruits shipped to America in 1782 (Corvisier 1970, p.610).

[10] Our discussion is based on the muster rolls we have digitized. See (Corvisier 1970) for a complete listing of signatures and the types of information that is associated with it.

[11] We refer to it a "basic information" because it is the minimal amount of information that must be present so that we can include an observation in our analysis.

[12] Supplementary information is for example a recruit's religion, his occupation or the occupation of his father. See subsection 2.6 for details.

[13] The reason why we digitized only the years of enlistment is that ages are in the vast majority of cases given as integers, so it is only possible to calculate the year of birth, not the exact date of birth.

[14] Dates of creation are taken from (Corvisier 1970).

[15] The "ethnicities" associated with a regiment are taken from (Corvisier 1970).

that we chose 1756 is that we observe already N=185 enlistees in 1756 in the regiment Royal Deux-Ponts and N=40 observations for the regiment Bouillon. Since these numbers are higher than the corresponding number of observations in all other regiments combined where the year of enlistment is smaller than the year of creation of the regiment, we do not think that these observations are inconsistent but reflect some initial recruitment. For the regiment "Royal Deux Ponts", it is known that enlistments happened before the official establishment (Tröss 1983, p.15).
- The regiment "Royal Lorraine" was created in 1744 out of the militia of Lorraine (Corvisier 1970, p.85). By inspection of the years of enlistment, 87.12 percent of recruits enlisted before 1744, so discarding those observations (N=1,015) does not appear to be reasonable. We suspect that the information about the recruits might have been copied from militia documents.

Enlistments after 1786 are also eliminated (N=17). Two observations are dropped because of inconsistencies and 35 observations are dropped because they report enlistment in multiple regiments.

In the vast majority of cases, the date of enlistment is noted without any further amendment (N=102,177)[16]. However, the muster rolls sometimes differentiate between the date of *recruitment ("engagé",* N=15,761) and the date of *enlistment ("enrolle"* N=3,682*)* and/or the date of *arrival*[17] *("arrive",* N=3,794*)* of an individual. The *recruitment* is the establishment of a contract between a recruit and an official from the regiment (Corvisier 1968, p.58). The actual *"enlistment"* happens when the recruit arrives at the regiment (Corvisier 1968, p.59). Corvisier (1968) also notes that for Grenadier companies, it is often unknown whether the date given is the date of recruitment or the date when the soldier entered the Grenadier company.

In our data, additional supplements are found, e.g. "in service since", but it is infeasible to discuss every single supplement here[18]. In absence of additional information on how to

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[16] Corvisier suspects that without any supplement, in most cases the date of recruitment is recorded: *"[...] assez souvent une simple date qui semble le plus souvent être la date d'engagement".* (Corvisier 1968, p.86).

[17] Arrival is often not specified in more detail, in rare cases the addition "at the regiment" or "at the depot" can be found.

[18] In combination or independent of the other supplements, the term "*recrue"* is also present (N=4,391). In 42 cases, the registers state *"recrue provinicale"* (signature 1 Yc715). The difference between the recruitment years is two years in one case, one year in 29 cases and zero years in 12 cases. We ignore the information about the provincial recruitment. In N=43 cases, the addition *"controlle"* is added. We ignore the information.

deal with these amendments, we decided to **ignore**[19] the all supplements and treat the individual-level data as measured at the given date.

6.2.2. Age at enlistment

As noted in Komlos (2003), the ages reported in the muster rolls do not necessarily reflect the age at the time of enlistment: But rather: *"For purposes of calculating the date of birth, it is crucial to note that the age of the soldier pertains to the date at which the registers were created. However, after the registers were begun, new recruits were continually added to the registers. For these new entrants, the age pertains to their date of enlistment, and not to when the registers were started […]"* (Komlos 2003, footnote 7.) He uses the same data source (muster rolls of the French army), but mostly[20] .different signatures compared to us. So, we can expect a selective up-coding of ages in our muster rolls, too.

Before we calculate the ages at enlistment, we made some minor corrections to the data: Ages are in the majority of cases[21] (N= 158,680) provided as integer numbers. In some cases, ages are given as age in years and a number of months (N=42) or age as a decimal number (N=297). These ages are rounded to the next integer age. The observations where the ages are given as "X to X+1 years" (N=28) are rounded to the larger integer age. Recorded ages above 86 Years are discarded (N=6). Two observations are dropped because of inconsistent or vague statements. For two observations, the year of enlistment is missing, and it is calculated as "year of birth + age in the registers".

A crucial information to detect the amount of up-coding and to calculate the correct years of birth are the dates of creation of the muster rolls, discussed in the next subsection.

Date of creation of the muster rolls

We digitized a year found on the specific cover sheets of the muster rolls. An officer supervised the confection of the rolls and had to undersign a standardized cover sheet, often adding a date to his signature. We consider this to be a candidate for the date of

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[19] The data provides some evidence that this strategy is reasonable: In N=20 cases, a year of recruitment was digitized as well as a year of arrival at the regiment. In 5 of these cases, the difference in years is zero. In 13 cases, the difference is 1 year. In one case, the difference is 2 years. But in another case, the difference is 13 years. Finally, in one case only the decade of arrival (1740ies) was readable, with an enlistment in 1733. This implies a minimum difference of 7 years and a maximum difference of 16 years. These last two observations are eliminated from the dataset.

[20] The signatures 1 Yc7, 1Yc 13 and 1Yc15 are present in our data as well as in Komlos' data.

[21] The cases where the age is missing but can be calculated from the other variables is found at the end of the paragraph. In some cases, the ages were written out in French (N= 3,740) but converted to integers during the digitizing.

creation. However, in the muster rolls we digitize, the cover-page may also be missing entirely or a cover sheet is present but not filled out. In some cases, a standardized cover sheet is not available, but simply the name of the regiment is given on a front page, as well as a year.

Fortunately, (Corvisier 1970) contains a collection of the dates of creation[22] for each register. We compare the dates of creation in our data to Corvisier's (1970) work and we find that the dates we digitized are largely[23] in accordance with the dates by Corvisier (1970). For a subset of the regiment "Royal Italien", (specifically signature 1 Yc875), we cannot distinguish the registers based on the available information[24]. Since the registers were created at different dates, we assumed the oldest date available in cases of ambiguity. Sometimes, additional dates are found on the cover sheet that are neither dates of creation nor dates of arrival. Those dates are ignored.

Calculation of the age at enlistment.

We calculate the age at enlistment using the following expression

$$age_E = \begin{cases} age_R - (Date_C - y_E), & if\ y_E < Date_C \\ age_R, & if\ y_E \geq Date_C \end{cases}$$

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[22] In Corvisier's (1968 and 1970) works we could not find an explanation whether the years given on those sheets are the actual years of creation of the muster rolls. We cannot exclude the possibility that the dates on the cover sheets are instead the dates after a *"renouvellement"* of the registers. *"Renouvellements"* happened frequently if troop composition changed, after the end of wars of when the registers became too old. (Corvisier 1968, p.13). Corvisier (1968, .11-12) mentions a case where the date after the signature corresponds to the date of *"renouvellement"*. The officers copied the information from the old registers to the new ones, and they were supposed to adjust the ages accordingly. Corvisier (1968) believes that often, this new up-coding did not take place. *"Lors du renouvellement des contrôles les majors ou aide-majors, s'ils recopient les noms, surnoms et lieux de naissance des hommes figurant sur les contrôles précédents, doivent par contre modifier leurs âges. On constate que souvent ce n'est pas le cas."* Corvisier (1968, p.73). For additional details on the *"renouvellement"*, see (Corvisier 1968, p.13-15 and 72-73). A copy of the registers was sent to Versailles respectively to the *"conseil de la guerre"* (Corvisier, 1968, p.10-11). This date of arrival is often found in our data, sometimes in combination with a date after the signature. The mean difference between the supposed date of creation and the date of arrival (if both are present) is 0.31 years (with a minimum of 0, a median of 0 and a maximum of 3). So we consider it unnecessary to double check our results using the dates of arrival where available in combination with the date of creation.

[23] We digitized different dates for the following signatures: one-year difference: 1 Yc269 ("La Dauphine"), two-year difference: 1 Yc437 ("Lally"), three-year difference: 1 Yc450 ("La Marck"). In case of conflict, we use the dates provided by Corvisier (1970). A special case is a 6 -year difference in the aforementioned "auxiliary company" (1 Yc869). The sheet they are listed on stipulates the date the company was sent to America in 1982. Corvisier also recognizes that they were sent to America in 1982, but subsumes the company under the first register created in 1776. This difference is irrelevant for us since this sheet contains years of birth directly.

[24] The problem is that the registers for "Royal Italien" were combined out of existing registers in a disorderly way. (See Corvisier, 1970, p.113-114).

Where:

- age_E is the age at enlistment
- age_R is the age given in the registers
- $Date_C$ is the year of creation of the registers
- y_E is the year of enlistment

Applying this calculation our data, the mean age shifts down from 24.76 years to 22.24 years. However, this approach does not yield convincing results: 0.39% of observations (N=587) have an age at enlistment that is negative or zero. In addition, 6.32% of observations (N=9,576) have ages between 1 and 15 years. This is highly implausible compared to the distribution of ages found in Komlos (2003, table 1), where Komlos reports 0.1% of ages below 16, which is the official age of admission (Corvisier 1968, p.74). Also, in our data exist companies that would consist almost *exclusively* of recruits with ages smaller than 16 if ages were up-coded as described above. This is also highly implausible. Consequently, we consider it unfitting to adjust all ages[25].

We now investigate whether the criterion proposed by Corvisier (1968) to determine those observations that have been up-coded produces more plausible results. Corvisier (1968) argues that if the ages decline in the registers starting from the head of the company, those ages are up-coded. If the ages do not decline, the ages are the ages at enlistment[26].

Using this criterion, we determine[27] the existence of trends in those registers where ages below 16 are prevalent (at least 1 percent of recruits per company). The basic assumption remains that the age at enlistment is calculated according the formula above. But for those recruits who are members of a company with more than 1 percent of "low" ages, we assume that the age originally recorded is the age at enlistment, if *in addition* the ages do not decline as Corvisier (1968) noted. This strategy produces a much more sensible distribution of ages compared to either using the age in the registers *always* as the age at

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[25] The signatures where we detect most of the implausible ages are either in a register (1 Yc710) of the regiment "Piémont" where the companies are mixed together (Corvisier 1970) and in two registers of the ancient regiment "Carignan", that was combined with the "Gardes Lorraines".

[26] *"L'âge indiqué est tantôt l'âge à l'engagement, tantôt l'âge au moment de l'établissement du contrôle. On peut s'en rendre compte de la manière suivante. Les soldats étant classés par ordre d'ancienneté dans la compagnie [...] si l'âge indiqué décroit de la tête à la queue de la compagnie, il est évident qu'il s'agit de l'âge à la date du contrôle. Sinon, c'est l'âge à l'engagement. De toutes façons, pour les hommes inscrits à la suite, l'âge indiqué est toujours l'âge à l'engagement."* (Corviser 1968, p.113).

[27] Based on a visual inspection of the scatterplot of ages against the position of a recruit in a company.

enlistment, or applying the up-coding formula to the whole dataset, as we tried first. The number of observations having an age of enlistment that is negative or zero is now down to 0.08% (N=121), and observations with ages between 1 and 15 years are down to 1.81% (N=2.794[28]). Those observations are dropped. Since using the trends to determine which observations are up-coded produces the most sensible results, we use the age calculated this way as the age at enlistment.

Note that we checked whether our estimated trends in chapters 1 and 2 are affected by the method of calculation of the age at enlistment. The estimated trends are qualitatively identical if we either assume that the originally recorded age is the age at enlistment for all observations where the original up-coding formula yields ages below 16 years, or if we discard these observations. So, the influence of the calculation of the age at enlistment is minimal, but we are sure that using the method that is most faithful to Corvisier's (1968) original statement is the correct approach.

For 8 observations, the age as well as the year of birth and the year of enlistment are provided. Two of these observations are inconsistent and are dropped. For N=7,556 observations, no information on age was recorded. However, for a subgroup of (N=6,990) observations, the year of birth is recorded as well as the year of enlistment. We calculate the age at enlistment as "year enlistment-year of birth for these observations. This approach yields N=273 ages smaller than 16 that are eliminated from the dataset. Since we analyzed trends in heights in the main text, we also discard all recruits with an age at enlistment above 50 (N=798), as suggested in Komlos (2004). He argues that heights start to diminish after the age of 50 (Komlos 2004, p.163). 2,069 observations are deleted since the year of birth as well as the year of enlistment are missing, although an age has been recorded.

6.2.3. Years of birth

We calculated a soldier's year of birth as the difference between the year of his enlistment and the soldiers' age at enlistment. We find that the calculation of the age of enlistment as leads to a reasonable distribution of years of birth. In particular, treating all the originally recorded ages as ages at enlistment would produce implausibly early years of birth.

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[28] Note that this still substantial number of very young recruits may be explained by the presence of "enfants du corps". These are children of soldiers. It was allowed to enlist a few of those (Corvisier 1968, p.74, p.96) In our sample we could identify N=354 "enfants" with ages below 16 out of a total of N=955 observations designated "enfants" that we discard.

6.2.4. Height

French recruits of the “Ancien Regime” were measured in the system of “Pieds du roi”, “Pouces” and “Lignes”. We calculate the height of a recruit by converting[29] the “Pieds” and “Lignes” into “Pouces” (referred to as “French Inch” (Fi) from now on, as in Komlos 2003). N=581 observations have no recorded information on “Pieds” and are eliminated from the dataset, as well as N=3 observations with “Pieds” larger than 6. If no statement about “Pouces” is made, this can either mean that the information is missing, or that “Pouces” is in fact zero. It is infeasible for us to distinguish between a missing “Pouce” and a true zero. We recode the N=4 observations with missing “Pouces” to zero. N=7 observations with values larger than 12 “Pouces” are eliminated, as well as N=2 observations with implausible values and one observation with two different declarations of “Pouces”. The “Lignes” information is often missing. We assume that missing “Lignes” should count as zero. N=4 observations with values larger than 12 “Lignes” are eliminated, as well as N=2 observations with non-integer values for “Lignes”, which we consider implausible.

Measurement error in heights

Some remarks are required on measurement error in heights. Corvisier notes that cheating with respect to heights was very frequent[30]. We have some evidence of a possible random error in recorded ages, since some heights are recorded with the addition “around” (N=319). Since we used height as a dependent variable in the main text we do not discard these observations. However, we have also evidence on non-random errors in measurement. Those do not influence the estimation of coefficients of random variables, but they distort the level of estimated heights. We digitized heights that include designations that we interpret as “close to” (N=15), “above” (N=443) or “below” (N=7) certain values of “Pieds”. Because -depending on the research question- height levels may be of importance, we discard these observations.

In addition, incentives existed that encouraged soldiers to make themselves appear taller than they actually were. The obvious reason is that soldiers were paid a bonus proportional to their height: *“La recrue a intérêt à se grandir car, à l'argent du roi s'ajoute un supplément, le „pourboire”, proportionnel à la taille. L'ordonnance du 1er février 1763, reconnaissant l'usage, fixa un véritable tarif.”* (Corvisier 1968, p. 83). We can test this

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[29] 1 Pied=12 Pouces. 1 Pouce=12 Lignes. 1 Pouces=2.706667cm (Komlos 2003, footnote 5).

[30] *“Les tromperies sur la taille sont très fréquentes”*. Corvisier (1968, p. 83)

statement in our data for N=37[31] observations in the signature “Royal Italien” (1 Yc873), where information about a “pourboire” payment[32] is recorded. Corvisier (1968, p.83) argues that soldiers above 5 “Pieds”, 2 “Pouce” were paid 5 Livres for every additional “Pouce”. A regression of the payment on heights in inches yields a positive, albeit small and insignificant coefficient of 0.76 (p-value 0.11, robust standard errors[33]). That is, one additional French Inch is associated with an increase in payment of 0.76. What’s more, the same signature offers a total of N=1,654 observations where a payment scheme[34] is recorded. A regression of the total payment on height yields coefficient of 0.71 (p-value 0.00, robust standard-errors), similar to the one in the previous regression. Both coefficients are substantially below the value proposed by Corvisier (1968), but the direction of the effect is in accordance with Corvisier’s statement. However, this finding has to be taken with a grain of salt, since we do not know the payment of those soldiers where no payment is recorded. It is unclear whether a payment scheme was only recorded in cases of deviation from a default scheme, for example.

The precision of the heights recorded increases with the years of enlistment (table DA3), a particularity that cannot be found in the study by Schubert (2008) who finds constant precision, whereas Komlos (2003) finds at first increasing and later decreasing precision. Corvisier (1968, p.83) notes that the heights in records from 1716 are recorded in “Pieds” and “Pouces”, and in 1737, heights recorded in “Pieds”, “Pouces” and “Lignes” are more general.

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[31] Actually, 49 observations have an information on the “pourboire”, but only N=37 are as tall as 62 French Inches where the bonus described above applies (Corvisier 1968, p.83). Soldiers that where 61 French inches tall received only a constant “pourboire” of 5 livres according to Corvisier (1968).

[32] The unit of payment is unclear in our data.

[33] The p-value of the coefficient of height increases if standard errors are bootstrapped (N=1000 replications).

[34] Actually, the records even specify the intertemporal allocation of the payments. We use only the observations where we could calculate the total payment directly.

Table DA3: Rounding

Years of enlistment	"Ligne" not zero	Percent	N
1671-1709	43	2.8	1,541
1710-1719	418	5.6	7,506
1720-1729	1,089	9.7	11,282
1730-1739	3,596	25.8	13,960
1740-1749	9,232	25.9	35,684
1750-1759	11,227	47.1	23.821
1760-1769	9,381	44.6	21,043
1770-1779	12,718	56.4	22,538
1780-1786	8,539	59.3	14,406

Sources: See the text. *Notes:* "Ligne" not zero as a measure for rounding was used in Schubert (2008). Results are rounded to one decimal place.

Komlos (2004, p.161) notes that symmetric rounding does not lead to a systematic bias in the analysis, so we do not pursue the issue any further as we have no information on the details of the rounding process.

Truncation of the height distribution

A minimum height requirement (MHR) existed in the French Army (Corvisier 1968, 1979). If the MHR is not taken into account, OLS estimates of population parameters using height as the dependent variable will be biased and inconsistent (Cameron/Trivedi p. 543). Thus, we advise researchers to investigate whether the existence of the MHR could influence their research question.

6.2.5. Geographical and political information

The template used by the recruiting officers to enlist recruits demands that recruits provide their "locality" of birth (*"lieu de naissance"*), the corresponding "jurisdiction" (*"jurisdiction"*) and the "territory" of birth (*"pays"*). This information cannot be used without additional interpretation, since the muster rolls contains this information with a varying degree of accuracy. N=483 observations are discarded since no geographical information is available, as well as N=523 observations where the information could not be digitized[35] due to the lack of readability. For the remaining observations, we used a stepwise geocoding procedure, where we first harmonized the information about the territory of birth, then used the harmonized territory to identify the corresponding jurisdiction. For a subset of the data, we also tried to identify the location of birth, in

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[35] These observations were digitized in the first place since they contained information about ages or heights important for the preceding calculations. If neither heights nor ages could be read in the original documents, the respective observations were not digitized at all.

combination with the information about the (previously harmonized) territory and jurisdiction. We discuss our coding and interpretation of each of these aspects in a separate subsection.

The primary goal of our coding process was to transform the raw data into a useable dataset, the second goal was to reduce the heterogeneity with respect to the territorial information. Second, we wanted to ensure that recruits born in a specific location "X" are all assigned to the **same** territorial unit[36], provided that we can identify the locality of birth from the originally digitized handwriting. A third goal was to establish consistency between the various levels of geographical and political information. It is infeasible to discuss every aspect of the geographical information in detail, so we have to pick out examples to illustrate the aspects we consider important. Furthermore, we highlight the main assumptions we used in harmonizing the data. Readers are encouraged to review the original data and our coding-files for details and a double check. As far as research is concerned, it may be necessary to aggregate the territories we defined below into larger meaningful units. Whether this strategy is necessary depends on the specific research question. For example, we aggregated territories in chapters 1, 2 and 3 based on geographical and political proximity.

Territory of birth

We use the terminology "territory of birth" to highlight an interesting aspect of the data structure. There is a lot of ambiguity associated with the term *"pays"* found in the original data. For example, the reported level of the political or administrative unit meant by *"pays"* may differ, from "Holy Roman Empire" (HRE) only, to individual principalities within the HRE, from "Switzerland" only to individual "cantons" and so on. Furthermore, sometimes only landscapes are given as the territory of birth. We want to retain the territorial information on the most disaggregated level that we consider sensible. At the same time, our coding is supposed to ensure an internally consistent assignment of observations to territories. It was a challenging task to assign the recruits to a political "territory" for a number of reasons: First, there is obviously a substantial "between-state[37]" variation in the administrative division, so the recorded administrative division

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[36] This is not as obvious as it may seem, since a certain locality X might have been assigned to multiple territories in the raw data.

[37] State refers to the biggest political units. For example, Kingdom of France, Holy Roman Empire (without Italian parts), Italy, Switzerland.

is different for every state found in our data. Our choice is primarily guided by the division found in the raw data. We tried to retain this division as much as possible, while at the same time reducing the ambiguity of certain expressions. Our goal is to use an assignment procedure that does not lead to too many discarded observations and provides stable observational units (with respect to the territories) over the time period of enlistment found in our data.

The territorial concepts we use are based on maps. We mostly used modern historical atlases, and we used the political structure as it was in 1789 because for this date, the maps are most detailed[38], provided that these maps contain the relevant territories found in our raw data. Where unavoidable, we used maps pertaining to other years. Two principles apply to the geocoding in general, irrespective of the state of birth:

- First, if substantial parts of a territory changed possession during the time period we study, we tried to define these as separate "entities" in our data where possible.
- Second, N=22,528 observations do not have an information on the "territory" of birth, and we assigned a territory of birth based on the information about the jurisdiction and/or the location of birth.

We now discuss some of the state-specific definitions of "territories" we used, since there are peculiarities whose handling we have to clarify.

Alsace

Starting in 1648, the Kingdom of France started to incorporate most parts of the Alsace until 1697 (Köbler 2007, p.164). Yet, the imperial laws where not nullified until 1789/1790[39] (Köbler 2007, p.164). As a result, we choose the territorial division of the Alsace as of 1648. We divide the Alsace into imperial counties, (prince-)bishoprics, imperial cities, imperial abbeys, "lordships" and territories held by imperial knights.

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[38] In addition, we do not know whether the recruits reported the political affiliation of their location of birth at the time they were born or at the time they enlisted.

[39] *„Gleichwohl blieb das E. bis 1789/1790 als […] Frankreich die deutschen Reichsgesetze offiziell aufhob und die Reichsgrafschaften und Reichsherrschaften annektierte […]"* (Köbler 2007, p.164). ["E." refers to the Alsace. Alsace is "Elsass" in German.]

Lorraine

Formally, the Duchy of Lorraine was part of the "Upper Rhenish Circle" of the HRE, but we treat it as a separate entity[40] within the Empire.

Kingdom of France

Multiple layers of administrative divisions existed in the kingdom of France, and they did not necessarily overlap[41]. We choose a data driven approach and assign the observations to *"Gouvernements"*[42] since we find that recruits in the vast majority of cases report these as their territory of birth. These *"Gouvernements"* designated under the name of provinces[43]. Corvisier (1968, p.77) notes that the use of *"Généralités"* became more frequent in the second half of the 18th century, an observation we do not share as far as our data are concerned. We find a total of 6 observations[44] where only the *"Généralité"* was recorded as territory of birth. Since we were not able to obtain a modern-day map that depicts the *"Gouvernements"* on a sufficiently detailed level, we mostly resorted to using a set of historical maps. Our primary source is (Robert de Vaugondy et al 1757), and as an overview we used (de l'Isle, 1741). Our definitions of the provinces "French Flanders" and "French Hainaut" that border on the Spanish/Austrian Netherlands only include the French parts, not those parts of "Flanders" and "Hainaut" that were in possession of the Habsburgs. Today's French départements "Savoie" and "Haute-Savoie" are assigned to Italy, since they were part of the "Duchy of Savoy".

We also assign to the Kingdom of France the "Tree Bishoprics[45]" (Metz, Toul, Verdun) that was a French possession since 1552 on the border to Lorraine, the Duchy of "Bouillon", a

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[40] *"Lothringen, Savoyen und das Hochstift Basel zählten sich nur bedingt zum Kreis"* (Köbler 2007, p.485).

[41] *"[...], la France se subdivise en de multiples circonscriptions qui, très souvent, ne coïncident pas, ayant été instaurées à diverses époques dans des buts non moins divers"* (Sellier and le Fur, 1997 p.20),

[42] After the French revolution, these were called *"anciennes provinces"* (Sellier and le Fur, 1997 p.21).

[43] *"Sous l'Ancien Régime, on les désigne couramment sous le nom de provinces."* (Sellier and le Fur, 1997 p.20). Masson (1984, p.13) has a more restricted interpretation: *"Certains auteurs font coïncider les provinces avec les gouvernements au nombre d'une trentaine, d'autres font état d'un plus grand nombre de provinces"*

[44] Schubert (2008) analyzed data on French recruits sampled from the "Contrôles des troupes", too. He categorized the territories of birth differently compared to us. He uses the concepts of *"Généralité"* (and *"Subdélégation"*) (Schubert 2008, p.120). However, compared to our data, he sampled from different muster rolls and in some cases also from different branches of service (Schubert 2008, p.189-190). Where he samples "ordinary" soldiers like we did (and not members of the *"militia"*), the years of enlistment do to a very large extent not overlap with our data. This could explain the difference in the recorded information. Komlos (2003) uses provinces instead (see p.163, table 1 and p.172, map 1).

[45] Since the territorial structure of the *"Three Bishoprics"* changed throughout the century due acquisitions of additional villages (see maps in Wolfram and Gley, (1931)), we approximate the territory by the *"Généralité de Metz"* in 1789. Note that Sellier and Le Fur (1997) provide maps that show the equality of the

French protectorate since 1693, on the border to the Spanish/Austrian Netherlands (Köbler 2007, p. 81).

Special attention must be paid to the territorial gains and/or losses at the border of the Kingdom of France during our period of study. We try to approximate substantial territorial gains and losses by defining the lost or gained territories as separate entities. For the eastern border of France, we use (Leisering 2009, p.81) and (Boutier et al. 2011, p.144). These territories are: On the border of the Spanish/Austrian Netherlands: the "Foret d'ardennes" (today's Canton "Givet" and parts of the canton "Revin"), a region around Tournai, a region around Ypern. On the border to Lorraine, we single out the areas around "Montmedy", "Stenay" and "Clermont-en-Argonne", since these were neither part of Lorraine nor the "Three Bishoprics".

Finally, we take into account territorial gains of the Kingdom of France *within* its territory (Leisering 2009, p.81). We set apart the "County of Charollais" (gained 1648), the "Principality of Dombes" (gained 1523 and 1762) and the "Principality of Orange" (gained 1702/1713) from the other provinces.

Holy Roman Empire

We divide the "Holy Roman Empire" (HRE) into territories that were *"reichsunmittelbar"*[46]. Our primary guideline to determine whether a territory is *"reichsunmittelbar"* is Köbler (2007), in combination with the maps we used. Some special cases of territories must be explained in more detail:

- We did not separate territories without full *"Landeshoheit"*, that are sometimes singled out on maps from the territory that exerts the *"Landeshoheit"* for them[47].
- We coded territories that are jointly governed by more than one sovereign as separate entities[48], provided that we can identify such a territory from the maps.

"Généralité de Metz" and the *"Three Bishoprics"* (see maps: *"Gouvernements et Intendances en 1789"* and *"La Lorraine et L'Alsace en 1789"*). Our source for the *"Généralité de Metz"* is Arbellot (1986).

[46] Actual or judicial persons that were not subordinated to a ruler but the king (Ploetz 1999, p.409). We ignore any division of power within a given territory, for example *"Landsassen"*, (lower ranks of the nobility that were subject of a ruler (Ploetz 1999, p.299)).

[47] This concerns for example territories carved out of existing territories to support (illegitimate) children of the ruler, like *"Hessen-Rothenburg"* (Köbler 2007, p.279).

[48] As an example, consider the *"Sovereignty Lebach"*. The territory was in possession of four sovereigns jointly (Köbler 2007, p.364).

In general, it should be noted that these cases are rare in our data. In reality, a chosen administrative classification may not be stable over time: Single or small groups of villages may change possession[49] , in particular in the HRE. We cannot track such changes and are therefore limited to taking mayor territorial changes into account. Territories that were dissolved during our time of study are split up into parts, if our maps allow us to do so[50]. If a ruler of a territory inherits another territory in our time of study, we treat the inherited territory as a separate entity if possible[51].

In some cases, the territorial information is ambiguous, in particular if we cannot infer the territory of birth from the locality of birth or the jurisdiction. Territories may bear an identical or similar name compared to an "Imperial Circle[52]". In such cases, if we have no other useable information, we recode the territory of birth to the level of "Imperial Circle". We also recode to the "Imperial Circle" if the information about the territory of birth is too vague. In cases where territories of the same name are part of different "Imperial Circles" and we have no further information, we recode to the Imperial Circle" where the majority of the territories are located[53]. Furthermore, we interpret the designations *"Franconie"* (N=639) and *"Suabe"* (N=1,398) as designations of imperial circles, for the "Franconian Circle" and the "Swabian Circle" respectively. data. As far as the "Burgundian Circle" is concerned, since we were not able to obtain a modern-day map that depicts the historical division of the Spanish/Austrian Netherlands on a sufficiently detailed level, we resorted to using a set of historical maps. Scattered possessions of the Electorate of Trier in the eastern part of the Spanish/Austrian Netherlands are not taken into account since we could not acquire a map with adequate[54] attention to detail.

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[49] See for example, the unification of the previously unconnected parts of the *"Three Bishoprics"* over the course of the 18th century (compare the maps in Wolfram and Gley (1931)).

[50] The prime example in our data is the *"County of Sponheim"*, that was split up in 1707/1776 (Köbler 2007, p.676-677).

[51] A prominent example is *"Hanau-Lichtenberg"*, that was inherited by "Hessen-Darmstadt" in 1736 (Köbler 2007, p.251). We treat "Hanau-Lichtenberg" as a separate territory throughout our period of study.

[52] For example, *"natif de Bavière"* may mean "born in the Electorate of Bavaria", or "born in the Imperial Circle of Bavaria". The "Circle of Bavaria" contains additional territories apart from the Electorate of Bavaria. If a recruit claims to be *"born in Bavaria"*, without further information, we assign the recruit to the imperial circle.

[53] For example, most *"Nassau"* territories are part of the "Upper-Rhenish Circle" but few are part of the "Lower Rhenish–Westphalian Circle". We proceed in the same way if the territory of birth is called *"Palatinat"* (Pfalz). This can mean multiple territories in different imperial circles, but without further information, we assign the observations to the "Electoral Rhenish Circle" (N=1,034).

[54] Essen et al (1927) lists these possession as contested, and the level of detail in this map is not high enough to single out all possessions. It had been possible to identify these possessions by using the "Ferraris map" (Ferraris 1777), but due an extreme attention to detail in this map, the marginal costs of singling the possessions out clearly outweighs the potential gains.

Finally, we have to discuss the coding of some "Imperial Cities": In the HRE, there existed ecclesiastical territories named after a city and the city itself was an imperial or free city, that is, a **distinct** territory[55]. In such a case, if we cannot identify the locality of birth, we assign an observation to the **larger** territorial unit, which is always the ecclesiastical territory. We observed that ecclesiastical territories are in some cases designated by the location of residence of the respective bishop[56].

Italy

Since we were not able to obtain a modern-day map that depicts the historical division of the Italy on a sufficiently detailed level, we resorted to using a set of historical maps. We divide Italy into the territories found in (Robert de Vaugondy et al 1757). Supplementary information in (Drago and Boroli 1997) was also used. Territorial changes in northern Italy due wars are accounted for. These the territorial changes between Savoy/Piemont and the Duchy of Milan are *approximated* by "regions" found in (Robert de Vaugondy et al 1757).

Switzerland

We divided Switzerland into *"Cantons, "zugewandte Orte"* and *"gemeine Herrschaften"*. The basic map we used is Amman and Schnib (1951, p.31 "Die Eidgenossenschaft 1536-1797".) Two designations of territories need special attention: Territories named *"Basel"* and *"St.Gallen"*. Multiple territories with these names existed at that time: *"Basel"* can mean either the *"Bishopric of Basel"* or the *"Canton of Basel"*. If we cannot identify the jurisdiction or the location of birth[57], we assign the observation to the *"Canton of Basel"* for the following reasons: The *"Canton of Basel"* was itself a territory that did **not only** consist of the City of Basel (see Amman and Schnib (1951, p.52). Additionally, *"Canton of Basel"* was an actual part of Switzerland, not a *"zugewandter Ort"* like the *"Bishopric of Basel"* (Köbler 2007, pp.44-45). Finally, the *"Bishopric of Basel"* is often designated *"Bishopric of Porrentruy"* in our data, after *"Porrentruy"*, the locality of residence of the bishop (Köbler 2007, p.44).

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[55] These are (Köbler 2007): in the Holy Roman Empire: Augsburg, Bremen, Kempten, Köln, Regensburg, Speyer, Worms and in Alsace: Strasbourg.

[56] For example, the "Prince Bishopric of Speyer" is called "Bishopric of Bruchsal" in our data. Bruchsal was the place of residence of the bishop (Köbler 2007, p.674). This fact helped us to some extent to distinguish "Imperial Cities" from corresponding ecclesiastical territories.

[57] Note that if the location of birth is given as *"Basel in Switzerland"*, we also assign it to the *"Canton of Basel"*.

The other case are territories named *"St. Gallen"*. This can either mean the *"Imperial City of St. Gallen"* or the *"Bishopric of St. Gallen"*. It is important to distinguish these two territories since a false assignment may lead to incorrect inferences. If the information recorded is *"born in St. Gallen in Switzerland"*, we assign an observation to the *"Bishopric of St. Gallen"* since it is a larger territory. However, if the information is *"born in St. Gallen in St. Gallen"*, we assign the respective observations to the imperial city since the it lies within the borders of the bishopric.

Jurisdiction

After we harmonized the information on the territory of birth, we tried to identify the "jurisdictions" of birth. It is not entirely clear what the term "jurisdiction" refers to and how the recruits respectively the record keeping officers understood it. Corvisier (1968) provides some evidence[58] that the jurisdiction may refer to feudal, administrative or judicial constructs (from our experience bearing the name of a city of town). Yet, Corvisier (1968) also notes that most officers used the non-compromising term *"jurisdiction"* and that the interpretation of the term *"jurisdiction"* may be different across people. However, we interpret the jurisdiction – where applicable- as a larger city or town, or in cases where it is obvious, as a territory itself. In cases where the original information about the territory of birth alone was not sufficient to assign an observation to a specific territory, we now use the information on *"jurisdiction"* and territory of birth combined to determine the territory of birth[59].

Location of birth

Recruits were asked to provide their "location" of birth ("lieu de naissance") among the aforementioned geographical information. What the recruits or the recruiting officers meant by "Lieu" is not entirely clear, and different interpretations exist. Komlos (2003) interprets it as "village or town of birth". Schubert (2008) does not study the locality of birth. Komlos (2003, p.161) also adds an important supplementary interpretation*: "[...] the recorded town of provenance was perhaps not the actual municipality from which the*

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[58] *"[...] l'élection, bailliage, seneschaussée ou chatellenie, dans le ressort desquels ledit lieu sera situé"* (Corvisier 1968, p.9). *"Par exemple on voit qualifier « élection », systématiquement toutes les juridictions dont dépendent les lieux de naissance. Reconnaissons que c'est assez rare [...]"* (Corvisier 1968, p.59).

[59] Two exemptions apply: We did not recode a territory based on the "jurisdiction" if the "jurisdiction" is an imperial city without a territory (and no corresponding ecclesiastical territory exists, see below) or an enclave without territory. In our opinion, because of the ambiguity associated with the term "jurisdiction", the information about it is best viewed as supplementary.

recruits originated, but might have included its environs." Corvisier (1968, p.68) adds a complementary interpretation. He believes that the recorded locality of birth may also refer to the *locality of baptism*[60] of a recruit. We assume that the smallest unit that is meant by location of birth is a village or town[61], because we cannot track the location of every settlement in Europe.

We did **not** try to identify locations of birth in the whole dataset. Rather, we only tried to identify locations of birth for a subset of the data. For the remainder of observations, we only harmonized the information about territories and *"jurisdictions"*[62], and checked the data for obvious errors[63], but we did not try to identify localities of birth (table DA4), even if they were provided in the raw data.

Table DA4: Treatment of locality of birth information

State	Locality of birth coded?	State	Locality of birth coded?
Holy Roman Empire[64]	Yes	HRE	No[65]
France	Yes	Ireland	No
Italy[66]	Yes	Scotland	No
Switzerland	Yes	Eastern Europe[67]	No
United Provinces	Yes	England[68]	No
Denmark	Yes	Spain	No
Countries with few observations[69]	Yes	Countries with few observations[70]	No

Sources: See the text.

Observations where there is information about the jurisdiction or location of birth available, but no information about the "territory of birth" was recorded, as well as observations where we could not identify a territory of birth without using the

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[60] For N=10 observations in our data, the locality of baptism is recorded in addition to a locality of birth.

[61] Yet, we try to account for integrations of villages to larger cities or into other villages.

[62] We checked the jurisdictions for these observations, since in particular for Ireland, counties are provided as jurisdiction.

[63] For example, we looked for German-sounding names of localities if the state is given as "Spain".

[64] Including Alsace, Lorraine

[65] The information about the locations of birth was **not** used for the following parts of the HRE: All lands of the Bohemian Crown (N=2,266) and all observations where the original territory of birth was given as "Holy Roman Empire". Concerning these latter cases, some observations that could be identified in a quick sweep of the respective observations are discussed in section 2.5.4.

[66] Including Corsica

[67] Consists of Poland, Livland, Latvia, Courland, Russia and Hungary.

[68] Including Wales.

[69] Denmark, Sweden, India and Norway

[70] Balkans (Slavonia, Dalmatia, Croatia, Serbia, Banat of Temeswar, Wallachia and the Republic of Ragusa), America (English and French colonies in Northern America and the islands in the Caribbean), Africa (anything south of the Mediterranean Sea, Portugal, Island of Majorca, Island of Corfu, Island of Malta, Island of Minorca, Ottoman Empire, unknown British colonies, Finland, unknown French colony, Island of Guernsey

information about the location of birth although it was recorded (N=3,999) are both treated separately from those where we could identify a territory of birth in the previous coding steps. The coding of those observations is discussed in the following section separately since we coded these observations using stronger assumptions than those stated so far.

The following discussion therefore refers **exclusively** to the states listed in table 4 where we tried to identify the locations of birth. We geocode[71] the locations of birth taking into account the information about the harmonized territories of birth and jurisdiction of birth. In cases where the original "territory of birth" information combined with the "jurisdiction of birth" was insufficient to determine the territory of birth, we use information on the location of birth, jurisdiction and the original territory of birth together to determine the territory of birth and location of birth.

Corvisier (1968, p.60) mentions an important aspect of the information about the location of birth: The orthography of the names may be phonetic, an issue that complicates the identification on localities of birth. As a result, same location of birth might have been spelled differently, depending on the pronunciation of the recruit. This phonetic orthography was also noted by Hudlet (2004). We use common sense in assigning the locations of birth in phonetic cases, and if we are largely unsure, we do not assign a location of birth. In assigning recruits to a specific locality of birth, we had to make some assumptions:

- If a location of birth is not found in a historical map due to insufficient accuracy of the map, but can be located with the help of contemporary maps, the political assignment is based on the position of the location of birth relative to settlements that can be found on the historical maps.
- In cases of contradictions between stated locality of birth and *"jurisdiction"* of birth and/or territory of birth, the information on the location of birth is considered to be more reliable. This does not apply to cases where the location of birth and the

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[71] The information about the names of locations of birth is primarily provided by modern day administrative shapefiles (see references) in combination with historical atlases that provide the source for the political assignment of locations of birth. As far as today's Belgium, Luxembourg and Netherlands are concerned, we used data from an open source project since the official administrative shapefiles we had at our disposal were not sufficiently detailed.

"jurisdiction"/territory of birth are more or less obvious contradictions. Those cases are excluded (N=1,096).

- If multiple settlements bearing the same name exist within a given territory of birth, we assign a recruit to the one that is closest to the stated *"jurisdiction"*. If settlements with the same name exist within a stated territory, but we do not have additional information, we did not assign a location of birth (N=7,044). On the other hand, if one of the localities is an imperial city, we assign the observation to the imperial city (N=55), and if the stated locality of birth has the same name as the capital[72] city of a territory, we assign the observation to the capital city (N=635).
- If a *"jurisdiction"* and a location of birth can be identified, but are in our opinion too far apart geographically, we did not assign[73] a location of birth. Nevertheless, we keep these observations since recorded *"jurisdiction"* and locality of birth are not contradictory (N=876).
- If a location of birth that can be identified and is not part of the stated territory, but close to the border of this territory, we used the same principle as stated in the previous section with respect to jurisdiction *"jurisdictions"*. In particular, if the locality of birth is located "close" to the territory stated by the recruit, we assume that the locality of birth is stated correctly and recode the territory accordingly.

Treatment of sparse and ambiguous spatial information

In this section, we discuss the treatment of observations where the available geographic information about the recruits' locations and territories of birth are sparse or ambiguous. Cases where only a short statement is made, like *"born in X"*, without any further comments, or a statement *"born in X in Germany"*[74] are the most prominent example. It is paramount that the reader understands that we quickly skimmed over these observations and we did not apply the same level of scrutiny as before. The reason is that without constraints[75] on the candidates for the possible locations of birth, searching all candidates in a reasonable amount of time does not appear feasible to us. As a result, in most cases, we had to resort to strong assumptions in order to be able to identify territories and/or

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[72] By capital city we mean either the administrative capital or the city of residency of the sovereign.

[73] We made this decision since we cannot exclude the case the stated location of birth does not correspond to the one we identified but corresponds to a settlement closer to the stated "jurisdiction" that we did not find on a map or in a shapefile.

[74] *"Allemagne"* in the original data. Cases where the original territory of birth was given as "Holy Roman Empire" are also contained in this category.

[75] In the preceding sections provided by the information about the territory and the *"jurisdiction"*.

localities of birth. It should be noted that the principles stated beforehand are modified to some extent. In particular, we now ignore the possibility that multiple settlements of the same name exist, and assign the observation to the most prominent settlement available.

- As a general principle, if the original data only state *"born in X"*, and X is the name of a territory as well as the name of city within the same territory, we **assume** that *"born in X"* refers to the territory only[76]. This is true irrespective of whether the name of the city is unique (N=1,941) or not (N=2,119).
- In N=1,286 cases[77], we assume that the recorded locality of birth refers to a capital city.
- In N=408 cases, we assume that the recorded location of birth refers to an imperial city even if multiple settlements with the same name exist.
- For recruits from France, it could also be the case that they provided the name of the *"Généralité"* they were born in instead of the location of birth, since *"Généralités"* were also named after cities[78]. In such a case of ambiguity, we chose to we assign the observation to the city and the corresponding "historical province". The reason is that we rarely find the *"Généralité"* as the territorial concept in our raw data (see subsection 2.5.1.3), so we believe that recruiting officers were consistent in not assigning recruits to *"Généralités"*.
- If we can identify a location of birth but multiple settlements bearing the same name exist, we assign the observation to a specific state (but we do not assign a specific location of birth within the state) if all settlements are located in the same[79] state. If not, we do not assign a state.
- Finally, in N=2,968 cases[80], we assign a location of birth that is more plausible[81].

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[76] For example, we interpret *"born in Trier"* as being born in the *"Electorate of Trier"*, while we interpret *"born in Trier in Trier"* as *"born in the city of Trier in the Electorate of Trier"*. This does of course not apply to imperial cities as they are territories themselves.

[77] N=920 cases are *"Paris"*.

[78] See Arbellot (1986).

[79] N=952 are assigned to France, and N=699 to the HRE, N=122 to Italy. N=231 cannot be assigned to a state. Minor numbers of observations are assigned to other territories in our data.

[80] These observations are marked in our dataset, so researchers not comfortable with the stated assignment principle are encouraged to discard these observations.

[81] For example, *"born in Tournay"* was interpreted as *"born in Tournai"*, a city in Belgium, although a small village named *"Tournay"* in the French Pyrenees also exists.

Summary of the geocoding procedure

We now sum up the results of the results of the **entire** coding procedure. We could assign **at least** a state in N=146,212 cases, but even taking all the geographical information into account, there still remain cases where we cannot identify at least a state of birth. These observations are discarded (N=3,467). The quota of identification of localities of birth under the aforementioned assumptions is 62%.

Most of our recruits were born in the Holy Roman Empire, followed by the Kingdom of France and Italy. On the side of the observations where we did not code the locations of birth, most recruits are from Ireland (table DA5).

Table DA5: Treatment of locality of birth information

State	Locality of birth coded?	N	State	Locality of birth coded?	N[77]
Holy Roman Empire[82]	Yes	76,138[83]	HRE	No[84]	3,005
France	Yes	35,307	Ireland	No	7,674
Italy[85]	Yes	13,136	Scotland	No	2,607
Switzerland	Yes	3,417	England[86]	No	1,702
United Provinces	Yes	766	Spain	No	1,097
Countries with few observations[87]	Yes	138	Eastern Europe[88]	No	871
			Countries with few observations[89]	No	354
Total	Yes	128,902	Total	No	17,310

Sources: See the text

Finally, it should be noted that during our coding process, we were surprised by the attention to detailed exercised by certain recording officers and/or recruits in providing

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[82] Including Alsace, Lorraine.

[83] Coded cases only.

[84] The information about the locality of birth was **not** used for the following parts of the HRE: All lands of the Bohemian Crown and all observations where the original territory of birth was given as “Holy Roman Empire”.

[85] Including Corsica

[86] Including Wales.

[87] Denmark (N=58), Sweden (N=50), India (N=21), Norway (N=9).

[88] Consists of Poland, Livland, Latvia, Courland, Russia and Hungary.

[89] America (English and French colonies in Northern America and the islands in the Caribbean, N=91), Portugal (N=72), Balkans, N=79 (Slavonia, Dalmatia, Croatia, Serbia, Banat of Temeswar, Wallachia and the Republic of Ragusa), Africa (anything south of the Mediterranean Sea, N=33), Island of Majorca (N=21), Island of Malta (N=22), Ottoman Empire(N=11), Island of Minorca (N=7), Island of Guernsey (N=7), Island of Corfu (N=5), unknown British colonies (N=2), Finland (N=1), Unknown French colony (N=1), Island of Jersey (N=1) and Mauritius (N=1).

information about the locality of birth. Note that Corvisier (1968) draws the same conclusion based on his study of the records[90].

6.2.6. Supplementary Information

Occupational titles

The occupation of the recruit and/or the occupation of his father[91] were recorded in some cases. In N=10,587 cases, only the occupation of the recruit was recorded, in N=5,609 cases, only the occupation of the father of the recruit was recorded, and in N=1,398 cases, the occupations of both were recorded. Corvisier (1968) warns that it is easy to confuse whether the stated occupation is the one of the recruit or his father[92]. However, he also notes that the recording officer may have thought that the social status of a recruit was sufficiently recorded this way, if the recruit has the same occupation as his father[93].

All occupational titles are in French[94]. We unified the spellings[95] and we assign the occupations to classes according to the "History of work information system[96]" that is based on (van Leeuwen et al. 2002). The "History of work information system" offers an internet based information system that allows to search for occupational titles and assigns a HISCO-code[97] as well as an English translation. Due to the nature of the information recorded in our data, we need to make some simplifications to facilitate the coding:

- As with localities of birth, we sometimes have to assume that the spelled occupation is phonetic.

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[90] *"[...] on est frappé de la connaissance relativement bonne qu'avaient les Français de leur géographie administrative, tout au moins dans leur région, dès le début du XVIIIe siècle."* (Corvisier 1968, p.70).

[91] In some cases, we suspect that the occupation of the mother was recorded. However, we placed every occupation of a parent into the category "father's occupation".

[92] *"[...] on peut très bien confondre: « X, fils de Y laboureur » ou « X, fils de Y, laboureur » [...]"* (Corvisier 1968, p.77)

[93] *"L'officier chargé du détail a pu penser que l'état social de la recrue était suffisamment fixé ainsi, le fils exerçant souvent la même profession ou activité que son père."* (Corvisier 1968, p.77)

[94] We ignore amendments like *"former"* or *"was"* that were digitized along with the occupational title. In cases where we could only find a female version of the occupational title, we nevertheless coded the respective occupation.

[95] Occupations are sometimes abbreviated: *"laboureur"* as *"lab"*, *"cordonnier"* as *"cord"*, and so on.

[96] http://historyofwork.iisg.nl/index.php, accessed 24.11.2016 and 25.11.2016 and 22.01.2017

[97] Note that we did not check whether the provenances used in the database correspond in the time they cover to our period of study or whether the job designations are from countries corresponding to the countries we study.

- If a recruit provides multiple[98] jobs, and we cannot find the exact same designation with both jobs in the database, we choose one of the occupations at random.
- In cases where a job was described using a "composite title[99]" and we cannot find a corresponding composite occupational title in the "History of work information system", we drop the "detailed" part of the job description and look for the broader job in the database[100]. Corvisier (1968) warns that using an occupational title in a general sense is something uncommon in the 18th century[101], but in lack of a better classification, we cannot do better that to use a broad definition of an occupation.
- In cases where the HISCO-database distinguishes between master and apprentice jobs (a distinction rarely found in our data), we assign the coding of the apprentice job if the two HISCO-codes differ.
- If we cannot find a HISCO-classification in the database, we have attempt to translate the job and assign it to a HISCO-code based on the verbal description of the HISCO-classes that accompanies[102] the database
- If multiple "subgroups" for the same occupational title exist in the database, we assign the one that we consider more appropriate based on the verbal description of the "subgroups".

Special attendance must be paid to the occupational title *"sans vacation"* [sic!]: Corvisier (1979, p.144) points out these problematic aspects of the recorded information: An occupation listed as "*sans vacation*" may either mean that a person is sufficiently rich and does not need to work or that he is actually without a profession. Furthermore, even if wealthy citizens joined the infantry, these were likely "declassed" ones, who had lost their

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[98] These cases are extremely rare in our data.

[99] As an example found in our data and also noted by Corvisier (1968) and available in the HISCO-database, consider the occupational title *"cardeur de laine"*, which would literally be translated into *"Wool carder"* (translation taken from the HISCO-database) while *"cardeur"* literally means *"carder"* (translation taken from the HISCO-database). They receive the same occupational code in the database. Corvisier (1968) notes concerning these and similar cases: *"Un nombre considerable de mots désigne des professions voisines. Ils sont le plus souvent dérivés du nom d'un outil ou de la matière travaillée: cardeur de laine, de chanvre, de filoselle... On sait également à quel stade de la fabrication des tissus les hommes travaillent: cardeur peigneur, tireur, retrousseur de laine...."* (Corvisier (1968, p.79)

[100] However, we did not assign any HISCO-code if the occupational title is too ambigous. For example, the title *"maréchal"* alone could refer to the military occupation or be an abbreviation of *"maréchal-ferrand"*. The same is true for *"fabricant"* (manufacturer) and *"faiseur de"* (maker of) if we cannot assign an occupation based on the manufactured product.

[101] *"Notons encore qu'on ne rencontre qu'exceptionnellement ces vocables au sens très general qu'affectionne l'époque contemporaine comme ouvrier, artisan, employé et même commis sans autre précision. Ces abstractions n'étaient pas encore familières à l'homme du XVIIIe siècle"* (Corvisier 1968, p.79).

[102] http://historyofwork.iisg.nl/major.php accessed 24.11.2016 and 25.11.2016

status (Corvisier 1979 p.144). Corvisier (1968) also notes that often, the designations *"sans profession", "manouvrier", "journalier"* and a missing occupational title have the same meaning[103]. However, he also adds that this occupational title can refer to a member of the *"bourgeoisie"* as well[104]. Since codes for *"manouvrier", "journalier"* are available in the HISCO-scheme, we code these accordingly. We also created a joint category for *"sans profession*" and *"sans metier"*. All observations without any recorded occupation will be assigned to a separate category.

Another issue arises with the term *"laboureur"*. A HISCO-classification of the term can be found and it refers to a *"agriculturalist – plougher"* in Belgium. However, Corvisier (1968) notes that this term is very vague and does refer more often to an agricultural occupation, than it indicates a social status[105]. What's more, Corvisier warns of attributing the term *"cultivateur"* (peasant in the interpretation of a French historian) to the recruits designated *"laboureur"* in general[106]. Corvisier thinks that the term *"laboureur"* should only be equated with *"cultivateur"* in some regions[107]. Another definition can be found in (De Vries 1976) that also supports the notion that in some regions the term may not refer to unskilled workers: *"[…] the richer laboureurs of northern France become a caste of labor-hiring, money-lending grain speculators"* (De Vries 1976, p.83). As a result, we do not classify "labourer" in the HISCO-scheme, but we treat it as a separate category. One soldier is designated an *"Invalide"* and therefore eliminated from the dataset.

We could not assign a HISCO code in N=707 cases for soldiers' occupations and in N=454 cases for the fathers' occupations.

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[103] *"Tantôt ils reçoivent la mention « sans profession » ou « sans vacation », tantôt leur signalement reste muet à ce sujet. Il est assez facile de se rendre compte que bien souvent l'absence d'indication professionnelle, la mention « sans profession » ou les mentions « manouvrier » ou « journalier » sont équivalentes."* (Corvisier, 1968, p.78)

[104] *„Toutefois il serait imprudent de s'en tenir là, l'absence d'indication professionnelle ou la mention « sans profession » pouvant s'appliquer également à des bourgeois même dans le dernier cas."* (Corvisier, 1968, p.78)

[105] *"Cependant on trouve le terme de laboureur employé dans un sens qui est le plus souvent bien vague et qui se rapporte à l'activité agricole plus qu'à l'état social."* (Corvisier 1968, p.79).

[106] *"On commettrait une lourde erreur d'appréciation si on donnait systématiquement à ce mot le sens de cultivateur aisé qu'il a dans le nord de la France et que Georges Lefebvre a popularisé."* (Corvisier 1968, p.79).

[107] *"Il est plus prudent de n'attribuer le sens de cultivateur aisé aux laboureurs que dans les régions où ils fournissent un nombre restreint de recrues, c'est-à-dire essentiellement les pays du nord de la France."* (Corvisier 1968, p.79).

At this stage, we do not classify the HISCO categories into the HISCLASS-scheme that assigns each HISCO-code to a social class, but we aggregate the occupations according to the HISCO-"majorgroups[108]" (table DA6).

Table DA6: Distribution of occupations

	Soldiers occupation		Father's occupation	
HISCO-majorgroup	N	Percent	N	Percent
Unknown or not recorded	134,934	92.3	139,659	95.5
Production and related, transport[109]	7,245	5.0	3,264	2.2
"Sans vacation"	2,121	1.5	16	0.01
"Laboureur"	708	0.5	1,383	1.0
Professional, technical and related	395	0.3	225	0.2
Agricultural, animal husbandry and forestry workers, fishermen and hunters	339	0.2	629	0.4
Service	326	0.2	359	0.3
Sales	58	0.0	372	0.3
Student	36	0.0	0	0.0
Bourgeois	35	0.0	189	0.1
Clerical and related	7	0.0	55	0.0
Pupil	6	0.0	0	0.0
Administrative and managerial	1	0.0	21	0.0
Disabled individual	0	0.0	25	0.0
Retired or private gentleman	0	0.0	14	0.0

Sources: See the text. *Notes:* "Sans vacation", "Laboureur", "Student" "Retired or private gentleman", "disabled individual" and "Pupil" are not part of the original HISCO classification, but are found in our data. Results are rounded to one decimal place.

Our findings that most soldiers have a social background that is not limited to the lower strata of the population (compare the relatively high number of production workers if an occupation is recorded and the fairly low number of "unskilled" workers, provided that one interprets "laboureur" and "sans vacation" as such) is in line with Lynn's (1997, p.324-325) statement that: *"The outside world may have considered common soldiers to be the dregs of society, but Corvisier's sample suggests that they were the sons of solid working class and peasant families".*

We study the occupational mobility for those observations where we have information on the fathers' as well as the soldiers' occupations (N=1,397): In 62.4% of cases, the soldiers' occupation falls into the same HISCO-majorgroup used in table 6 as their fathers'

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[108] Categories with the same general verbal descriptions of the tasks performed are aggregated. This refers to the majourgroups 0 and 1 ("Professional, technical and related workers") as well as to the majourgroups 7,8 and 9 (Production and related workers, transport equipment operators and labourers")

[109] This category contains the ambiguous occupational titles *"manouvrier"* and *"journalier"* but only N=39 respectively N=22 observations.

occupations. We interpret this result as an indication of limited occupational mobility. In any case, both occupations may be valid proxies for one another.

Religion

The religion of soldiers was recorded on a non-systematic basis. Corvisier (1968, p.136) notes that religions were exclusively recorded for foreigners. As an example, Corvisier (1968) mentions that the religion of Alsatians was recorded systematically in German regiments, however the religion was not recorded for other recruits of French nationality serving in these regiments. Religion was recorded in N=31,328 cases in our dataset. The incidence of recorded religion varies considerably between regiments (table 7).

Table DA7: Recorded religion

Regiment	Percentage of religion recorded	N
Royal Deux-Ponts	91.3	7,817
Saint-Germain	74.3	2,489
Nassau	62.2	4,456
Royal Hesse-Darmstadt	50.1	9,952
La Marck	48.3	15,554
La Dauphine	42.4	3,169
Salm-Salm	30.9	13,204
Royal Suédois	30.0	2,859
Bouillon	13.4	5,531

Sources: See the text. *Notes*: N refers to the total number of observations in a regiment. Regiments not listed in the table have no religion recorded. Results are rounded to one decimal place.

The distribution of the religions indicates a strong overweight of Catholics in the regiments (table 8) that may not be representative of the general population.

Table DA8: Distribution of religions

Religion	N	Percent
Catholic	23,500	75.0
Lutheran	5,222	16.7
Member of the reformed church	2,333	7.5
Calvinist	140	0.5
Evangelist	84	0.3
Protestant	26	0.1
Unassignable[110]	11	0.0
Greek Church	6	0.0
Anabaptist	3	0.0
Lutheran converted to catholic	2	0.0
Huguenot	1	0.0
Total	31,328	100

Sources: See the Text. *Notes:* Results are rounded to one decimal place.

In this section, we discuss supplementary information that is found in our data but that we did not recode or use in our analysis. The information is mentioned for completeness only. We did not rectify the digitized information thoroughly, so the numbers stated here represent an upper bound of the information that can actually be used, since it is plausible that we were not able to interpret all the recorded information correctly, if we checked it thoroughly.

Location of recruitment

Schubert (2008) uses the location of recruitment as an indicator of the localities of birth. Since we have tried to identify localities of birth directly, we do not use the information about the locations of recruitment. Corvisier (1968) states that the locations of enlistment are rarely recorded. In our dataset, we have an information on the localities of recruitment in N=9,465 cases. Yet, the information content is limited. localities of recruitment are in the vast majority of cases provided only as the name of the location[111] without an information about the territory of recruitment. If one tried to interpret the information, one would have to resort to very strong assumptions in terms of which locality is meant, in particular if multiple locations of the same name exist. Because we do not feel

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[110] Some information has been digitized, but we could not identify the meaning.

[111] For example: *"in Strasbourg"*

comfortable in identifying the localities of recruitment without very strong assumptions, we do not delve deeper into the topic.

Locality of residence

In N=100 cases, in addition to the location of birth, the settlement where the recruit lived before enlistment is recorded. Corvisier (1968) notes that this information was not asked for on the template of the muster rolls, but recorded by conscientious officers[112] if the location of birth and the locality of living differed. This number is too low to justify the attempt to identify locality of living and gauge the effect of "movers" on selection into the service. In our dataset, the location of residence of at least one parent was recorded in N=140 cases. This number is also too low for an analysis. As a result, we do not pursue the issue of "movers" any further. However, we hypothesize that the low number of cases where the locality of living is recorded may also be interpreted as evidence that recruits did not move considerably from their locality of birth before enlistment, so recording it was not deemed useful at that time.

Ethnicity

In addition to the geographical information, the *ethnicity* of the recruit is recorded in some cases. We treat the ethnicity as a separate information compared to the geographical information if it was recorded in a different cell of the muster roll (most notably in the same cell that contains the name of the recruit). We checked for an approximate consistency of the ethnicity and the assigned territory of birth. In N=29 cases, we find striking differences between the ethnicity and the assigned territory of birth. We eliminate these cases from the dataset.

"Son of"

As an information about the origin of a recruit, the ethnicity of his father is sometimes (N=245) stated in the sense that the recruit is designated "son of a (plus an ethnicity)". The recruits designated as such are indeed sons of migrants in the sense that the assigned state does not match the ethnicity of the father. The sons of Irishmen with N=180 observations are the largest group, and in N=143 cases these sons of Irishmen were born

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[112] *"Ce renseignement n'est pas exigé dans les en-têtes imprimés, mais quelques majors consciencieux, allant au-delà de ce qui leur est demandé, tout au moins dans les contrôles, l'indiquent lorsque lieu de naissance et domicile sont différents."* (Corvisier 1968, p.71-72).

in France. Unfortunately, the number of observations is too small for an analysis, but further research in this direction may be interesting to scholars in other disciplines.

Rank

Military ranks were digitized in a non-systematic fashion[113] and should therefore not be used in an analysis without a second look into the original data.

Reengagements

In some Regiments, reenlistments of recruits are recorded in the same cell as his first enlistment. We do not use the information.

6.3. Duplicates

The last data issue we have to tackle is the existence of duplicate or incorrect observations that have so far not been identified in our data. If duplicates exist, they will artificially inflate the number of actually sampled individuals and the inference on estimated parameters will not be correct since the actual number of independent observations will be overstated. The existence of duplicates is an issue that Corvisier (1968) states very clearly as not being an isolated phenomenon[114] with various causes. As an example, he mentions multiple enlistments by the same individual to collect the reward for enlistment. We interpret the following statement by Corvisier as an attempt to calculate the number duplicates: *"J'y ai dénombré 5.500 hommes environ pour près de 7.000 signalements."* (Corvisier 1968, p.55). His calculations refer to the regiment "Vivarais-infanterie" but we do not know of any study that assessed the existence of duplicates in our data. We interpret the above statement in the sense that 1,500 out of 7,000 observations are duplicates. Since we did not digitize given names and surnames[115] so we cannot identify duplicates based on names.

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[113] Except for Grenadiers that were always designated as such if they were recognized during the digitizing process.

[114] *"Une bonne partie des soldats est signalée plus d'une fois, soit parce qu'on a conservé les deux exemplaires du même contrôle, soit parce que ces soldats ont servi assez longtemps pour être présents au corps lors de la confection de plusieurs contrôles successifs, soit enfin parce qu'ils ont changé de corps."* (Corvisier 1968, p.54).

[115] For a difficulty associated with the term "surnom" in the time period of our sample, see Corvisier (1968, p.66)

Before we try to identify duplicates based on variables in the dataset, we discard a set of observations that were digitized twofold but were only recognized[116] as duplicates afterwards. These are N=1,594 cases in signature "1 Yc 874". Parts of this signature are copied together from other parts of the signature (see Corvisier 1970, pp.112-113) so it is no surprise we made an error in the digitizing.

In N=213 cases, we digitized statements like "error" or "double recruitment" made by the record keeping officer in the muster rolls. We discard the observations marked as such.

As and additional source of duplicates, we observed that recruits were transferred between companies (collected in three variables in our dataset). We digitized these transfers if they were recorded in the muster rolls. These serve an a very crude indicator of duplicate candidates[117]. If we define a dummy variable with value 1 if at least one of the transfer-variables is non missing. Using this indicator, N=19,860 recruits were transferred.

With this number as a starting point, we want to identify duplicates based on a suitable set of variables.

We believe that the most conservative strategy to identify duplicates is to define them in terms of the basic information in the data, that is based on the information on height (in Fi), age at enlistment, year of enlistment, year of birth, territory of birth, location of birth[118] and regiment[119]. We are convinced that we should not take supplementary information into account since these may not have been copied properly if a recruit was transferred or the recruit may not have stated the exactly same information if he enlisted twice for the reward. If we identify duplicates based on the aforementioned variables, N=17,315 observations will be identified as having one or more duplicates. This number

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[116] Note that in a lot of microfilms, individual pages of companies are often present more than once in consecutive images. If we recognized such a doubled page, based on a repeated pattern of information, we did not digitize it twice.

[117] Note that this in an inaccurate measure of duplicates, since it could be the case that a recruit is recorded with his given name and surname in two companies, but the basic information is only recorded in one company. Since we only digitized an observation if the basic information was available, not every transfer may constitute a duplicate in our data. In addition, the variables listed above contain not only within-regiment transfers, but also between regiment transfers, albeit with a substantially lower incidence.

[118] Here we use a variable that consists of the identified locations of birth where identification was possible and the original information in the other cases.

[119] We do not consider it prudent to identify duplicates only within a company. The obvious reason is the aforementioned transfer of recruits, but the there is another reason in the structure of the data: Companies may be mixed together, in the records (as is the case in our data for 1 Yc710 (Piémont), see Corvisier (1970, p.147)).

is remarkably close to our crude estimate based on the transfers to other companies, but still below Corvisier's estimate mentioned above.

We suggest to discard duplicates. We have to decide which of the observations defined as duplicates we wanted to drop. In terms of the aforementioned variables used to identify duplicates, it does not matter which of the observations we drop within a group of duplicates. Yet, since we only define duplicates based on a subset of variables, it may be the cases that for a pair or group of observations we identified as duplicates, one observation contains more supplementary information compared to the others. Since we want to retain as much information as possible, we keep the one observation that contains the most supplementary information for each pair or group of duplicates. As a result, we discard N=9,454 duplicated observations. In a final check of the dataset, we discarded another N=5 observations due to inconsistencies.

6.4. Some aspects of sample selection

In this paragraph, we provide a quick overview over aspects of the sample selection process that we cannot study directly using our data, but that need to be discussed to inform the reader about selection mechanisms that may influence the representativeness of our sample. During the period of enlistment found in our data, foreign troops were paid higher wages than national French regiments. In particular, *"[...] in the French army of the eighteenth century, pay for German, Italian and especially Swiss regiments was a little higher than for the French units"* (Corvisier 1979 p. 68). The usual pay was comparable to a peasant' income or that of a tradesman, but with service at the weekends and no unemployment risk (Corvisier 1979. p.69). All this may be a source of self-selection into certain regiments. Enlistment was possible as long as the language of command was understood (Chartrand 1997). As a result, in the second half of the 18h century, "German" regiments in the French army consisted to about one third of men from Alsace and Lorraine who were able to speak German (Corvisier 1979 p.114). Note that the recruitment of foreigners depended on the permission of the respective country`s sovereign (see Lynn, 1997 p.366-367 for examples).

6.5. Conclusion

This appendix provides a critical overview over the quality of a dataset constructed from muster rolls of the French army. We discuss the data re-coding that turned the original dataset into a dataset we consider useable for analysis. We provide a clear definition of regiments and special companies. We discuss the information content of the data, with a focus on the process of geo-coding. Where possible, we coded the occupations of recruits of their fathers into the HISCO-code. We give a short overview over supplementary information about recruits that was digitized but is not covered by us. We suggest a strategy to identify duplicate observations in the dataset. In addition, we provide a short overview over aspects of the selection into the military that are not directly quantifiable using our data. We conclude with Corvisier's (1968, p.57) reassuring conclusion about the *"controles de troupes"* in general as a source of information, that encourages further study of the data*: "Je pense toutefois que les contrôles de troupes offrent sur chaque individu enrôlé un faisceau de renseignements en principe comparable et même plus abondant que ceux qui accompagnent les actes d'état civil et les cotes d'imposition."*

Coding of supplementary data

The observations whose digitizing and recoding we described in the former part of the data appendix are not the only observations that were available. N=7,029 observations were digitized in addition, but we could **not double-check** these observations since we did not have the corresponding microfilm-copies at our disposal any more when we decided to double-check the data. For the sake of brevity, we only provide a report of the main aspects of the coding we carried out.

The supplementary dataset contains observations from five signatures: 1Yc445, 1Yc518, 1Yc519, 1Yc900, 1Yc901. The original dataset does not contain the names of the regiments digitized, so we assign the regiments based on Corvisier (1970). The dataset contains recruits from the regiments “La Marck”, “Gardes Lorraines” and “Royal Suédois”. We exclusively used the dates of creation of muster rolls reported in Corvisier (1970). The age at enlistment was always calculated according to the formula

$$age_E = \begin{cases} age_R - (Date_C - y_E), & if\ y_E < Date_C \\ age_R, & if\ y_E \geq Date_C \end{cases}$$

where all variables are identical to those described in the main text. Due to the fragmentation of the data, a more refined process was not possible. Only observations with ages at enlistment between 16 and 50 were kept in the dataset. We could not determine whether digitized information on the location of birth refers to the actual location of birth or the jurisdiction of birth. We choose a conservative approach and assume that the most detailed geographical information is on the “jurisdiction”-level. The same applies to the occupational information: We do not know whether the information refers to the occupation of the father or the recruit itself. We assume that the occupation of the recruit himself was digitized. After cleaning the dataset of implausible or inconsistent observations, duplicates and implausible values, N=5,782 observations remain that may be used in an analysis.

References for data appendix

Archival designations

1Yc7, 1Yc8, 1Yc13, 1Yc15, 1Yc96, 1Yc157, 1Yc158, 1Yc223, 1Yc257, 1Yc259, 1Yc296, 1Yc303, 1Yc304, 1Yc306, 1Yc374, 1Yc406, 1Yc407, 1Yc437, 1Yc446, 1Yc447, 1Yc448, 1Yc449, 1Yc450, 1Yc489, 1Yc510, 1Yc511, 1Yc512, 1Yc516, 1Yc517, 1Yc520, 1Yc523, 1Yc586, 1Yc587, 1Yc637, 1Yc638, 1Yc703, 1Yc704, 1Yc705, 1Yc706, 1Yc707, 1Yc708, 1Yc710, 1Yc711, 1Yc712, 1Yc715, 1Yc721, 1Yc784, 1Yc785, 1Yc786, 1Yc825, 1Yc826, 1Yc828, 1Yc833, 1Yc836, 1Yc837, 1Yc853, 1Yc863, 1Yc869, 1Yc870, 1Yc871, 1Yc872, 1Yc873, 1Yc874, 1Yc875, 1Yc935, 1Yc936, 1Yc955, 1Yc956, 1Yc957, 1Yc958, 1Yc959

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Germany: “Geographische Namen”, © GeoBasis-DE / BKG 2015. Downloaded from: https://upd.geodatenzentrum.de/geodaten/gdz_rahmen.gdz_div?gdz_spr=deu&gdz_akt_zeile=5&gdz_anz_zeile=1&gdz_unt_zeile=20&gdz_user_id=0 last access 15.09.2015.

We cleaned the file of any non-settlements.

Europe: “Community Centroids 2010”, © European Union/Eurostat 2016. Downloaded from: http://ec.europa.eu/eurostat/cache/GISCO/geodatafiles/COMM_PT_2010_SH.zip last access 05.04.2016.

We eliminated the centroids for France, Germany, Italy, Switzerland, Austria, Belgium Luxembourg and Netherlands since for those countries, we used the following files:

Polygon-data:

France: “GEOFLA® Communes 2011”, © INSEE/ IGN-F 2014. downloaded from: https://wxs-telechargement.ign.fr/oikr5jryiph0iwhw36053ptm/telechargement/inspire/GEOFLA_THEME-COMMUNE_2011_GEOFLA_1-1_SHP_LAMB93_FR-ED111/file/GEOFLA_1-1_SHP_LAMB93_FR-ED111.7z last access 01.05.2014.

Italy: “Communi 1991”, © ISTAT 2014. Downloaded from: http://www.istat.it/storage/basi_territoriali_2013/LimitiAmministrativi/Limiti1991/Com1991_WGS84.zip last access 01.05.2014.

Switzerland: „Generalisierte Gemeindegrenzen der Schweiz“ © Bundesamt für Statistik (BFS), GEOSTAT 2014. Downloaded from: http://www.bfs.admin.ch/bfs/portal/de/index/dienstleistungen/geostat/datenbeschreibung/generalisierte_gemeindegrenzen.Document.166578.zip last access 01.05.2014.

Austria: “Verwaltungsgrenzen 2015” © BEV - Bundesamt für Eich- und Vermessungswesen 2016. Downloaded from: http://www.bev.gv.at/pls/portal/docs/PAGE/BEV_PORTAL_CONTENT_ALLGEMEIN/0200_PRODUKTE/UNENTGELTLICHE_PRODUKTE_DES_BEV/VGD-Oesterreich_gst.zip last access: 30.05.2016.

All the aforementioned polygon-files were converted to point-files using the polygon centroid in QGIS versions 2.2-2.14.

Shapefiles from open source projects:

Point-data:

Belgium: “Places 2016” © OpenStreetMap contributors, Open Database 1.0 License, downloaded from: http://download.geofabrik.de/europe/belgium-latest.shp.zip last access 05.04.2016

We cleaned the file of any non-settlements and isolated dwellings.

Luxembourg: “Places 2016” © OpenStreetMap contributors, Geofabrik. Open Database 1.0 License, downloaded from: http://download.geofabrik.de/europe/luxembourg-latest.shp.zip last access 05.04.2016.

We cleaned the file of any non-settlements and isolated dwellings.

Netherlands: “Places 2016” © OpenStreetMap contributors, Geofabrik. Open Database 1.0 License, downloaded from: http://download.geofabrik.de/europe/netherlands-latest.shp.zip last access 05.04.2016.

We cleaned the file of any non-settlements and isolated dwellings.

All of the aforementioned files were -where necessary- reprojected in QGIS (versions 2.2-2.14) to the World Geodetic System 84 format(WGS84) and the joined together.

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Annotations to maps used in geocoding

Alter, Willi and Baumann, Kurt. Unknown date „Text für Vorl. Nr. 79, 80, 81, 82, 83, 84 - Die Herrschaftsgebiete um das Jahr 1350 - Die Herrschaftsgebiete um das Jahr 1450- Die Herrschaftsgebiete um das Jahr 1550- Die Herrschaftsgebiete um das Jahr 1650- Die Herrschaftsgebiete um das Jahr 1750- Die Herrschaftsgebiete im Jahre 1789“ [accompanies „Pfalzatlas“]

Unknown author: „Herrschaftsgebietes im Jahre 1789 – Zahlen- und Buchstabenschlüssel“ [accompanies Irsigler, „Herrschaftsgebiete im Jahre 1789“]

Unknown author: „Zahlenschlüssel zu den Karten Hessen um 1550 und Hessen um Jahre 1789“ [accompanies „Geschichtlicher Atlas von Hessen“]

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We first report the maps used to define the historical provinces of France. Note that we report only the main title of each map.

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Sr.Robert. 1752. „Partie meridionale du gouvernement genéral de Bourgogne-Gouvernement général du Lyonois“

Sr.Robert. 1752. „Partie méridionale du gouvernement général de Champagne““

Sr.Robert. 1752. „Partie septentoriale du gouvernement général de Bourgogne“

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Sr.Robert. 1753. „Gouvernements généraux du Berry, Du Nivernois, et du Bourbonnois“

Sr.Robert. 1753. „Gouvernements généraux de la Marche, du Limousin et de l’Auvergne“

Sr.Robert. 1753. „Gouvernements généraux du Maine et Perche, de l‘Anjou, de la Touraine et du Saumurois“

Sr.Robert de Vaugondy, fils. 1753. „Gouvernements généraux du Poitou, du Pays d’Aunis et de Saintonge-Angoumois“

Sr.Robert. 1753. „Gouvernements général de Picardie et Artois – Gouvernements généraux du Boulenois et de la Flandre françoise“

Sr.Robert de Vaugondy, fils. 1753. „Gouvernements général d‘Orleanois – La Beauce“

Sr.Robert. 1753 „Partie méridionale du gouvernement de Guinne – Gouvernement der Basse Navarre et Bearn“

Sr.Robert. 1753 „Partie orientale du gouvernement général de la Guienne“

Sr.Robert. 1754. „Gouvernement général de L’Isle de France“

Sr.Robert de Vaugondy, fils. 1754. “Gouvernement général de Provence”

In addition, we used the overview:

De l'Isle, Guillaume. 1741. „Regni Galliae seu Franciae Et Navarrae Tabula Geographica in usum Elementorum Geographiae Schazianorum accommodata; Cum Privil. Sacrae Caes Maiest. – Carte de Franceok danke" Homanniani Heredes, Norimb. [Nürnberg]

The following maps are used to define the territorial division of the Spanish/Austrian Netherlands.

Sr.Robert de Vaugondy. 1751. „Pays-Bas catholiques"

Sr.Robert de Vaugondy. 1752. „Partie meridion. Du Duché de Brabant - Le Comté de Namur"

Sr.Robert de Vaugondy, fils. 1752. „"Comté de Flandre"

Sr.Robert de Vaugondy, fils. 1752. „Partie septentrionale du Duché de Brabant"

Sr.Robert de Vaugondy. 1753. „Carte du duche de Luxembourg"

Sr.Robert. 1753. „Les Provinces-Unies des Pays-Bas"

Sr.Robert. 1754. „Comtés de Hainaut et de Cambresis"

Sr.Robert de Vaugondy. 1754. „La principauté de Liège et le duché de Limbourg"

The following maps are used to define the territorial division of Italy.

Sr.Robert. 1750. „Etat de l'église, grand duche de Toscane, et Isle de Corse"

Sr.Robert. 1753. „Partie méridionale du royaume de Naples"

Sr.Robert. 1750. „Partie occidentale de la Lombardie"

Sr.Robert. 1750. „Partie orientale de la Lombardie"

Sr.Robert. 1750. „Partie septentrionale du royaume de Naples"

Lebenslauf

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2010	Diplom-Volkswirt (Universität)
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München, 19.09.2017