The Decline in BMI among Japanese Women after World War II

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Abstract

The body mass index (BMI) of the Japanese is significantly lower than that found in other high-income countries. Moreover, the average BMI of Japanese women is even lower than that of Japanese men, and the age-specific BMI of Japanese women has decreased over time. Their average BMI at age 25 decreased from 21.8 in 1948 to 20.4 in 2010 whereas that of men increased from 21.4 to 22.3 over the same period. We examine the long-term BMI trend in Japan by combining several historical data sources spanning eleven decades, from 1901 to 2012, in order to determine not only when but also how the BMI decline among women began: whether its inception was period-specific or cohort-specific. Our nonparametric regression analysis generated five findings. First, the BMI of Japanese women peaks with the 1930s birth cohort. This means that the trend is cohort-specific. Second, the BMI of men outpaced that of women in the next cohort. Third, the BMI of Japanese children, boys and girls alike, increased steadily throughout the 20th century. Fourth, the gender difference in the BMI trend is due to a gender difference in the weight, not the height, trend. Fifth, these BMI trends are observed in urban and rural populations alike. We conclude that the BMI decline among Japanese women began with those who were in their late teens shortly after World War II.

1. Introduction

In recent decades the average weight of men and women throughout the world has been rapidly increasing, a phenomenon known as the global obesity epidemic (Ng et al. 2014). Conventional explanations for this trend include an increase in the availability of high-calorie food, an increase in the opportunity cost of preparing healthful food, a decrease in physical activity in an increasing use of motorized vehicles and an increasingly automated workplace, and a decrease in the medical costs of obesity (Cutler et al. 2003; Cawley 2010; Finkelstein and Strombotne 2010). In sharp contrast with this global trend, however, both the obesity rate and the average body mass index, or BMI, defined as (weight in kilograms) divided by (height in meters) ^{2}, among Japanese men and women are significantly lower than those recorded in other high-income countries. Moreover, the average BMI of Japanese women is even lower than that of their male counterparts (Finucane et al. 2011; OECD 2012), and the age-specific BMI of Japanese women has decreased over several decades (Takimoto et al. 2004; Funatogawa et al. 2008 and 2009; Sugawara et al. 2009). We calculate that the average BMI of women 25 years of age decreased from 21.8 in 1948 to 20.4 in 2010, whereas that of men increased from 21.4 to 22.3 over the same period. None of the conventional explanations for obesity epidemic account for this gender difference.

In this paper, we examine the long-term BMI trend in Japan based on a more suitable methodological framework, more detailed data analysis, and a more substantial database – one spanning the years 1901-2012 – than those used in previous studies in order to determine when and how this decline in BMI among Japanese women began. It is unlikely that the BMI of Japanese women has decreased throughout the history. The literature indicates that national income is positively correlated with BMI both cross-sectionally and longitudinally (Finucane et al. 2011; Floud et al. 2011). It naturally follows that there exists a certain turning point in history when the current declining trend began. We then consider the issue of whether the decline in Japanese women's BMI is a period-specific or a cohort-specific phenomenon. We also examine the extent to which the changes in average BMI can be attributed to changes in average height as opposed to average weight and whether there was a significant difference between urban and rural populations in regard to their BMI trends. The answers to these questions provide insights into the mechanism underlying long-term BMI trends not only in Japan but in modern societies generally.

This study combines two historical data sources: the National Nutrition Survey (NNS), for the years 1947-2012, and the School Health Survey (SHS), for the years 1901-2012. The NNS and the SHS provide height and weight data, measured by professional nurses, and these are among the best such data in the world in terms of the sample representativeness, accuracy, and time span. By combining these two data sources, we are able to provide a comprehensive picture of the Japanese BMI trend. Because it is highly nonlinear, we conduct a nonparametric locally weighted regression to delineate the origin of the BMI decline among Japanese women. The advantage of this approach is that it enables us to provide a detailed picture of the BMI trend immediately after World War II, a period for which few data are available. Parametric regression models depend heavily on the functional form, and in the cohort analysis of body weight, different specifications yield strikingly different results (Keyes et al. 2010).

Our analysis indicates that the decline in BMI among Japanese women is a cohort-specific, not a period-specific, phenomenon; the BMI of Japanese women peaks with the 1930s birth cohort. This is in sharp contrast with a drop in BMI due to the food shortage during World War II and its aftermath, which is period-specific and occurs among males and females in every age category. We also find that the BMI of men outpaced that of women in the 1940s birth cohort. This reversal, like the decline in female BMI, can thus be said to be a cohort-specific phenomenon.

2. Related Studies

A host of empirical evidence indicates that both the level and the trend of BMI in Japan are exceptional. Comparing recent age-adjusted adult BMI across 199 countries, Finucane et al. (2011) show not only that Japanese men and women alike have the lowest average BMI to be found among high-income countries but also that the average BMI of Japanese women is nearly as low as that found in low-income countries such as Cambodia, Laos, and North Korea (Figure 1).[1,2]

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[1] Underweight (BMI<18.5) is becoming a public-health concern in Japan because of associated high mortality, small-for-gestational-age (SGA) deliveries, and health conditions such as low bone-mineral density (Hozawa et al. 2008; Arimatsu et al. 2009; Harita et al. 2012). In 2011, the prevalence of underweight was 11.0% among Japanese women generally and 29.0% among Japanese women in their twenties (Ministry of Health, Labour and Welfare 2013). Nevertheless, Japan has among the highest longevity and among the lowest infant mortality rates in the world. The macro-level socioeconomic impact of the high prevalence of female underweight has yet to be quantified.

[2] Eating disorders are not driving these trends, as the prevalence of such disorders in Japan remains significantly lower than that found in Western countries (Chisuwa and O'Dea 2010), contrary to the widespread notion that low BMI in developed countries is largely attributable to eating disorders.

[Insert Figure 1 here]

Not only the level of but also the decline in BMI among Japanese women is a unique exception to the global obesity epidemic. Finucane et al. (2011), having reviewed BMI trends in 199 countries from 1980 to 2008, conclude that Japan is one of the nineteen countries where age-adjusted female BMI has not increased significantly. However, there is a paucity of cohort studies that cover a longer period based on population-representative data.[3] Long-term surveys similar to the NNS exist for other countries but began later. One of the earliest examples is the National Health Examination Survey, the first large-scale and population-representative anthropometric survey in the U.S., which began in 1959. American conscript-based data provide information on the height and weight of soldiers in the mid-19th century and are fairly representative of the population, but the coverage is limited to young men (Costa and Steckel 1997).[4]

Previous Japanese studies of BMI have been based on the aggregate data from either the

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[3] There are a few studies in the U.S. that find an increase in BMI among both males and females in every age category since 1959 (Komlos et al. 2009; Komlos and Brabec 2010, 2011; Lee et al. 2011). However, there is considerable disagreement as to when the rate began to soar. Vignerová et al. (2007), working with population-representative data on Czech children and adolescents from 1951 to 2001, find that the median BMI of females in their late teens significantly decreased, whereas that of their male coevals remained almost constant. Although this pair of trends is similar to those found in Japan, the significance of this similarity is unclear, since the two countries' paths have been radically different, Czechoslovakia having been under Communist rule from 1948 to 1989.

[4] As for children, a number of studies have examined both the long-term height trend (Vignerová et al. 2006; Bielecki et al. 2012; Núñez and Pérez 2014) and the height and weight trends (Zellner et al. 2007; Johnson et al. 2012; Kryst et al. 2012; Petranović et al. 2014).

NNS or the SHS, but not both. All of them concern specific age groups, and the majority focus on children and adolescents. Most studies of children are based on the SHS and find that the trend is upward for boys and girls alike (Hermanussen et al. 2007; Kagawa et al. 2011; Kagawa and Hills 2011). Kagawa et al. (2011), using the SHS to analyze BMI trends among schoolchildren throughout the entire 20th century, find a steady increase among both boys and girls. In contrast, NNS-based studies of young women find a downward trend in BMI since the 1970s (Takimoto et al. 2004; Sugawara et al. 2009). Funatogawa et al. (2008), drawing on NNS data on girls and young women from 1948 to 2005, conclude that while the BMI of girls increased over time, that of young women decreased. Regarding the long-term BMI trends of adults, Funatogawa et al. (2009), drawing on NNS data from 1956 to 2005, conduct least-squares regression of BMI on age groups, birth-cohort groups, and their interaction terms, and they conclude that the cohort effect is significant.

This study contributes to the literature in a number of ways. First, this is the first time that data on adult BMI shortly after World War II have been used in the analysis of the long-term BMI trends. The early years of the NNS (1947-1955) are indispensable for the declining BMI trend back to their origins. Funatogawa et al. (2009) also analyze BMI trends of Japanese adults, but they do not draw on NNS data prior to 1956.[5]

[5] Funatogawa et al. (2009) argue that their results demonstrate cohort effects, with the age-specific female BMIs peaking at the 1931-1940 birth cohort. This conclusion is derived, in fact, from the extrapolated BMIs for the early 1950s and is based on their linearity assumptions that both age effects and cohort effects are time-invariant and that the age-cohort interaction effect is constant throughout the 1950s. These assumptions, however, are not in line with previous findings that among young women the effects of age and cohort are highly nonlinear and time-variable (Funatogawa et al. 2008; Sugawara et al. 2009). Their

Average body weights in the NNS before and after 1956 are not directly comparable because after 1956 pregnant women were excluded. To address this concern, we adjust for maternity-weight gains.[6] Second, this study combines SHS and NNS data for the first time. Although the SHS are limited to students, combining the two data sources permits us to study long-term BMI trends among adolescents, throughout the first half of the 20th century. Third, we address potential selection bias in the SHS. Fourth, we employ an estimation method that allows us to address the issue of the highly nonlinear nature of the relationships among BMI, age, and cohort. Many of the existing Japanese studies use linear regression models that do not conform with the previous findings of strong nonlinearity in both child and adult BMI (Funatogawa et al. 2008; Sugawara et al. 2009; Kagawa and Hills 2011; Kagawa et al. 2011). Additionally, all of the aforementioned Japanese studies rely on BMI measures aggregated by rough age and cohort groups of five- to ten-year intervals, which prevent them from being able to provide a precise description of the BMI trend, especially shortly after the war. Our nonparametric approach also allows us to fully utilize data from this period. Lastly, we compare the BMI trends in urban and rural populations.

3. Data

Our sample is derived from the NNS and the SHS. These are cell-mean tabulated data and provide average height and weight by sex, age, and birth year. Because the average BMI of the sample is not reported, we define a "mean BMI" by mean weight (in

results for the later years indicate merely that cohorts born in the 1920s and 1930s were the peak cohorts when they were in their 50s and 60s.

6 Funatogawa et al. (2008) use the NNS prior to 1956 to study females up to the age of 25 but do not account for this potential problem.

kilograms) divided by the square of mean height (in meters). This section outlines these data sources and our definition of the cohort. Details on these data sources and the construction of the data set are provided in Appendix 1. We also include two small-scale data sources that provide prewar information (the Conscription Examination Data and the Teikoku Life Insurance Data), although we find that their contributions to our main results are limited. These additional data sources are also described in Appendix 2. Because the number of observations by sex and age is available only after 1972 in the NNS, we conduct no statistical inference in this study.

3.1. The National Nutrition Survey (NNS)

The NNS provides us with nationally representative annual data of height and weight on Japanese one year old and older from 1945 to the present. We use the NNS data from 1947 to 2012 because height was added to the NNS in 1947. Sample size varies greatly from year to year. In 1948, the sample size was approximately 39,000 individuals, or 6,200 households. By the mid-1960s, the sample size had increased to approximately 68,000 individuals, or 16,500 households. By 2011 the sample size had gradually decreased to 6,900 individuals, or 3,400 households. Katanoda et al. (2005) confirm that the NNS is nationally representative.

Height and Weight data in the NNS are accurate and free from the reporting bias associated with self-reports (Gorber et al. 2007): participants in the NNS remove their shoes before their height and weight are measured, by health professionals, and the weight of their clothing is factored in. Mean height and weight are reported by age for those aged 1-25 and by age group for those aged 26 or older. Age groups are mostly 5 or

10 years in length, but they vary considerably across survey years, and this fact makes comparison of surveys from different years difficult. To recover age-specific mean height and weight of individuals over 25, we use cubic spline, on the assumption that the reported mean value for an age group equals the mean value at the midpoint age of the age-group bracket. For example, the mean height of the age group 30-39 is regarded as the mean height for age 34.5. Because the oldest age bracket (e.g., “aged 80 and over”) does not have a midpoint, we use the actual age distributions of the men and women in this group, obtained from the Population Census, to calculate the mean ages. Because the Population Census is conducted only every five years, we use the Population Census of the year closest to the year concerned.

Because the reported mean of female weight in the NNS prior to 1956 includes pregnant women, we adjust for weight increase due to pregnancy on the basis of estimates of the average weight increase of pregnant women in Japan and the age-specific fertility rate in the year concerned. The details of the adjustment for pregnancy weight gain are provided in Appendix 1.

3.2. The School Health Survey (SHS)

The SHS began in 1900 as a nationally representative survey of Japanese students. We know of no other similar data source covering such an extensive time period. The SHS is based on the annual body measurements of students that all schools in Japan are legally required to record. Every year between April and June, school nurses measure the height and weight of the students in light clothes and unshod. Reporting errors are therefore minimal. The SHS provides us with nationally representative annual data on students from 1900 to the present from a randomly extracted sample of schools. The sample size is large. For example, the 2012 sample comprises 4.9% of all students, or 695,600, enrolled in 7,755 schools. Because the age-grade system has been strictly enforced since the amendment of the Elementary School Law, in 1900, almost all children in Japan start school at the age of six. In addition, only rarely does a student repeat or skip a grade in Japan. Because the SHS is limited to students enrolled in school, selection bias is naturally a concern. However, our view is that such bias, if it exists, is minimal, because since the early 20th century the school-attendance rate in Japan has been one of the highest among industrialized countries.[7] To minimize the selection problem, we exclude age groups with low school-attendance rates. The details of this sample exclusion are provided in Appendix 1. We do not use data collected in 1900 because in that year body weight was rounded off to the nearest kilogram.

3.3. Defining the cohort

The SHS is based on body measurements made between April and June, whereas the NNS is based on measurements made in either May or November, depending on the survey year. We redefine the birth cohort in order to analyze the two surveys in the same

[7] Japanese compulsory education began in 1886. By 1900 the attendance rate for children aged 6-10 years old had already reached 91% for boys and 72% for girls. In 1907, despite the extension of compulsory education to six years, the attendance rate reached 97% (Ministry of Education 1980). The attendance rate for non-compulsory middle school also rapidly increased during the early 20th century; in 1936, 92% of boys and 80% of girls had completed at least two years of non-compulsory formal education (Kikuchi 1997). In 1947, compulsory education was extended to nine years, and since 1948 the enrollment rate for compulsory education has always been above 99%. The enrollment rate for senior high school steadily increased from 48% for boys and 37% for girls in 1950 to 90% for boys and 92% for girls in 1974 (National Women's Education Center of Japan 2013).

framework. Another non-standard feature of the SHS is that, although age groups in the SHS are based on each student's age on the previous first day of April, the body measurements are not necessarily conducted in April. This time lag creates another discrepancy between the NNS and the SHS. In the regression analysis below, we take into account this discrepancy by adjusting the definition of "age" reported in the SHS. The details of the cohort definition and age adjustment are provided in Appendix 1.

4. Analysis

4.1. Age-specific BMI by cohort

Before turning to the nonparametric analysis, we discuss the descriptive characteristics of the two data sets. Figure 2 presents the mean BMI at ages 13, 25, and 40 by sex and birth year. The blue lines plot values calculated using the NNS, and the red lines are the fitted curves based on a quadratic least-squares regression. The green dots in the top row of Figure 2 represent the BMI values based on the SHS data. SHS values are slightly larger than NNS values because the timing of measurement relative to age is slightly later in the SHS. We adjust this time gap between the NNS and the SHS when we conduct the regression analysis, below. Because the NNS sample size is smaller than that of the SHS, NNS values fluctuate more than SHS values do. Overall, the NNS and the SHS describe highly consistent patterns, indicating the accuracy and representativeness of both data sets. Figure 2 shows the mean BMI for thirteen-year olds, boys and girls alike, steadily increasing over the past hundred years, with two exceptions: the 1930s cohort and the 1990s one. It was in 1943 that the children born in 1930 were thirteen years old; the sharp decrease in their BMI was no doubt due to the fact that they were suffering from a severe food shortage on account of the war.

[Insert Figure 2 here]

The mean BMI at age 25, presented in the middle row in Figure 2, reveals the gender difference in the BMI trend. While male BMI at age 25 continued to increase after World War II, female BMI at age 25 steadily decreased. Female BMI at age 40, shown in the right-hand panel of the bottom row of Figure 2, exhibits an inverse-U-shaped pattern. The red fitted quadratic curve for female BMI peaks with the 1937 cohort. In contrast, male BMI at age 40 steadily increased over the last sixty years.

4.2. Nonparametric regression

The aim of our nonparametric regression analysis is to illustrate how Japanese BMI varies by age and birth cohort without imposing any of the functional-form assumptions used in previous studies. The highly nonlinear nature of the BMI trend may not be fully captured by simple parametric specifications. Although various parametric regression models have been proposed for estimating effects of age, period, and cohort on various health outcomes, the identification of these three effects remains challenging (McKenzie 2006) and researchers have found that different models may yield strikingly different results (Keyes et al. 2010). For instance, causes of a difference in male BMI at the age of 25 between 1974 and 2009 could be either cohort-specific or period-specific: both differences in values and lifestyles by generation (i.e., the 1949 cohort vs. the 1984 cohort) and temporary events that occurred shortly before the observed years (i.e., the oil shock vs. the collapse of Lehman brothers) could account for the difference. Without parametric assumptions, our analysis aims not to estimate effects of age, period, or cohort but to visualize the movement of Japanese BMI in the age-cohort space.[8] This approach also allows us to discuss whether a particular movement in BMI is age-, period-, or cohort-specific by visually examining whether the movement occurs to everyone in certain age, everyone in certain time, or everyone in certain cohort.

We employ a locally weighted cubic regression of cell-mean BMI on two regressors – birth year and age. A local regression estimator has an advantage over standard kernel estimators in that it avoids boundary bias, that is, a flatter slope of regression estimator near the largest and smallest values of regressors. Although the historical span of our sample is exceptionally long, its coverage of the World War II period is limited; consequently there are many end points along the regressors around this period. Because illustrating the BMI trend immediately after the war as precisely as possible is crucial to our purposes, we employ an estimator that has an advantage in the boundary problem. To capture a highly complex movement of BMI across age groups and cohorts, we employ a cubic functional form rather than a linear or quadratic form.

The regression analysis is implemented as follows. Denote the local regression estimator of BMI as $bmi(x, z)$, where the two regressors, x and z, represent birth year and age, respectively. To obtain $bmi(x_0, z_0)$, the local regression estimator uses the information in the local neighborhood of (x_0, z_0). We report the estimates of BMI for the subset of integer grid points that range from birth year 1883 to 1993 and from age 13 to 72. Because of the concern for potential bias due to extrapolation, estimated BMI

[8] Because age, time, and cohort are linearly dependent, our choice of the age-cohort space is without loss of generality.

is reported only for integer grid points that have at least one observation within the distance of 1, with the following two exceptions. First, because we have a considerable amount of information on both the pre- and the post-war periods, and thus we can reasonably estimate BMI as interpolation rather than as extrapolation, the child BMI during the war period is reported even if there is no observation within the distance of 1. Second, we do not report estimated BMI in the neighborhood of a few prewar data points derived from the Teikoku Life Insurance Data. Although those prewar data enhance the overall accuracy of our nonparametric regression, there are not sufficient observations to permit a reliable estimation of the BMI trend of prewar adults.

Let *N* denote the number of cells~~observations~~ and subscript *i* stand for the *i*th cell. The locally weighted cubic regression estimator at (x_0, z_0) estimates unknown parameters *a* and *b* by minimizing

$$\sum_{i=1}^{N} K\left(\frac{d}{h}\right)\begin{pmatrix} bmi_i - a - b_{1,0}\bar{x}_i - b_{0,1}\bar{z}_i - b_{2,0}\bar{x}_i^{\,2} - b_{0,2}\bar{z}_i^{\,2} - b_{1,1}\bar{x}_i\bar{z}_i \\ -b_{3,0}\bar{x}_i^{\,3} - b_{0,3}\bar{z}_i^{\,3} - b_{2,1}\bar{x}_i^{\,2}\bar{z}_i - b_{1,2}\bar{x}_i\bar{z}_i^{\,2} \end{pmatrix}^2,$$

where $\bar{x}_i$ and $\bar{z}_i$ are $(x_i - x_0)$ and $(z_i - z_0)$, respectively, and $K(.)$ is a kernel weighting function with distance $d = \sqrt{\bar{x}_i^{\,2} + \bar{z}_i^{\,2}}$ and bandwidth h. The kernel function, $K(.)$, gives a non-zero weight for the 600 nearest observations regardless of data sources. We choose 600 so that the estimated BMI trend is sufficiently smooth but still maintains relevant movements in data. This choice is somewhat arbitrary, but our main findings are fairly robust to the choice of this number. In this approach, the bandwidth h is variably determined as the distance from (x_0, z_0) to its 600th nearest neighbor. For the 600 nearest observations, weights are given according to a tricubic kernel, $K(d/h) = (1 - (d/h)^3)^3 \cdot 1[i \in 600 \text{ nearest observations}]$, where 1[.] is an indicator function.[9]

The estimated BMI trend is shown in Figures 3(a) to 3(c). All of the graphs show the same estimated BMI by sex, conditional on birth year and age. The color spectrum indicates BMI. To assist the comprehension of the three-dimensional graphs, we present the same graphs from three different angles. Figure 3(a) provides a bird's-eye view of the graph. The X axis represents the birth year, and the Y axis represents age. The colored shapes in Figure 3(a) indicate the areas in the (birth year, age) space in which we report estimated BMI.

[Insert Figure 3 here]

To highlight gender differences, Figure 3(b) shows the graphs from an oblique angle. The graphs in Figures 3(a) and 3(b) clarify the fact that male BMI is increasing monotonically in both age and birth year, whereas female BMI is highly nonlinear. The irregular movement of female BMI trend is especially prominent in Figure 3(b). Female BMI increases with age up to the early teen years and then exhibits a significant decrease during the late teen years and the early 20s, followed by a resumption of the monotonic increase. The finding that the mean BMI increases with age for both boys and girls until the early teen years is consistent with previous studies undertaken in Japan (Hermanussen et al. 2007; Funatogawa et al. 2008; Kagawa and Hills 2011; Kagawa et al. 2011). The decline in female BMI during the early 20s is also found

[9] For more details of the methodology, see, e.g., Section 9.4. Nonparametric Local Regression (p.307) in Cameron and Trivedi (2005).

among Korean women (Kwon et al. 2007), although researchers in Finland and the U.S. report a monotonic increase in BMI with age for both sexes (Lahti-Koski et al. 2001; Komlos and Brabec 2010). The finding that male BMI is monotonically increasing in age and birth year is also consistent with previous studies from Japan and the U.S. (Yoshiike et al. 2002; Funatogawa et al. 2009; Komlos et al. 2009; Komlos and Brabec 2010; Lee et al. 2011).

Turning to the BMI trend over birth cohorts, which is most clearly shown in Figure 3(b), we find that child BMI increases steadily with birth year for both sexes, whereas adult female BMI shows an inverse-U-shaped trend in birth year, with its peak around cohorts born in the mid-1930s. This observation implies that although the remarkably low BMI of young women and the drastic reduction in BMI from the late teen years to the mid-20s is a recent phenomenon, the declining BMI trend dates as far back as women born in the 1930s.

Figure 3(c) shows the graphs from an even lower oblique angle. These graphs facilitate the comparison of the BMI trends of children and adults. The age-specific BMI of children increases with birth year throughout the 20th century without any significant gender difference, highlighting the fact that the BMI decline concerns only females who are in their late teen years or older.

Figure 3(c) also illustrates the effect of the war. For both sexes, a gutter runs along the upper right of the graph, corresponding to a drop in BMI during the first several years of the NNS. This gutter runs diagonally, rather than vertically, in the (birth year, age) space, and it is observed to be similar for males and females alike, including children. This fact indicates that this plummeting of BMI is not cohort-specific but year-specific, most likely reflecting the effect of World War II. Food shortages began during World War II (Ministry of Welfare Research Institute 1942) and continued through the early 1950s (Health and Nutrition Study Group 1998). This war effect contrasts sharply with the BMI decline among females, which is a cohort phenomenon concerning women born after 1930, more significant among younger than among older cohorts. In addition, the magnitude of the war effect is far smaller than that of the decades-long declining BMI trend among Japanese women.

4.3. Age-specific height by cohort

Because BMI is calculated from height and weight, a change in BMI can be decomposed to changes in height and weight. Figure 4 presents estimated height by sex conditional on age and cohort. Both graphs in Figure 4 indicate a steady height increase throughout the 20th century, except for the sharp drop around World War II and the recent diminution in the increase, consistent with previous studies (Hermanussen et al. 2007; Funatogawa et al. 2009; Bassino and Kato 2010; Kagawa et al. 2011). This height trend over cohorts is observed for both sexes, despite the gender difference in the BMI trend. This implies that the decline in BMI among Japanese women in the late 20th century was caused by changes in weight, not by changes in height.[10]

[Insert Figure 4 here]

[10] The graphs clearly indicate the negative effect of World War II on children's height. We refrain from discussing the war effect in detail because data limitations prevent us from measuring with precision the magnitude and the duration of the effect.

Because the three-dimensional figures are not suitable for comparing the levels of BMI and height by sex, the cohort-BMI profiles of estimated BMI and height at selected ages are reported in Figure 5.[11] Except for the case of children aged 15, in which the female BMI at age 15 is always higher than the male BMI at age 15 throughout the 20th century, the BMI of men was lower than that of women among the early cohorts, but male BMI outpaced female BMI shortly after the latter peaked, with the cohort born around 1940. This reversal of the two trends' relative positions is thus a cohort-specific phenomenon. Such a reversal is not observed in the panels of age-specific height.

[Insert Figure 5 here]

4.4. Comparison of urban and rural populations

It has been reported in the literature that in developing countries obesity as well as high average BMI are more prevalent in urban than in rural populations, whereas the opposite has been found to be the case in the U.S. (Patterson et al. 2004; Prentice 2006; Davis et al. 2011; Goryakin and Suhrcke 2014) and among teenage girls in Japan (Takimoto et al. 2004; Yamamura 2012). Because urban and rural areas in Japan have followed different economic growth paths and experienced different patterns of lifestyle changes, we examine whether these differences have led to different BMI trends.

The comparison is based solely on the NNS. Height and weight data by area type and/or

[11] The supplementary document contains the age-BMI profiles of estimated BMI and height at selected cohorts.

by household type are available in many survey years. Because in the majority of survey years height and weight data by municipality type are available, for these survey years we define urban areas as cities and rural areas as towns and villages. For the other years, urban and rural categories are coded as follows. From 1947 to 1951 there are disaggregated values of "cities" and "agricultural villages," and we regard the former as urban areas and the latter as rural areas. For the period 1957-1963, because only household-type disaggregation is available, we regard respondents in non-farm households as members of the urban population and those in farm households as members of the rural population. The years 1969-1972 are not used because no disaggregated values are reported either by area type or by household type. These categories are used to calculate mean height and weight by age and sex for urban and rural areas to create subsample data sets similar to the one described earlier and to carry out nonparametric regression analysis.

The resulting graphs are available in the supplementary document, and further details are available upon request. Our findings from the analysis are summarized as follows. First, urban residents are taller than their counterparts in rural areas regardless of age, sex, and cohort. Second, rural residents have higher BMIs than urban residents, although the urban-rural difference in BMI is not as robust as that in height.[12] Third, the temporary, period-specific decrease in BMI during the post-war period found in the previous full-sample analysis is prominent in rural areas but is much less evident in urban areas. This could be because a severe food shortage began before the end of the

[12] The urban-rural difference in BMI of working-age individuals is considerably less evident during the survey years in which the "farmer and non-farmer" grouping is used. This is probably because farm work is more labor-intensive than is non-farm work.

war in urban areas, whereas in rural areas the food situation was better than in urban areas immediately after the war but rapidly worsened. Finally, and most importantly, the gender-specific BMI trends are observed in urban and rural populations alike, including the consistent increase in male BMI and the presence of the peak cohort for women.

5. Conclusion

In this paper, we investigate when and how the BMI decline among Japanese women began. We combine historical data sources from 1901 to 2012. Our nonparametric regression analysis shows that the BMI decline can be traced back to females in their late teen years shortly after World War II.

Our study makes four additional important contributions to the extensive literature on BMI and obesity. First, highly nonlinear BMI trends exist at the aggregated level even in the very long run. This fact highlights the importance of long-term data and the need for analytical frameworks that can address the issue of nonlinearity. The nonlinearity revealed in our analysis, such as the complex relationship between the BMI trends of women and girls, cannot be captured by a simple parametric regression analysis with year, cohort, and year-cohort dummies used in previous studies.

Second, this study shows that cohort effects play a more significant and long-lasting role in determining national BMI trends than do period effects. This finding suggests a possibility that short-term policy interventions have a limited effect in altering BMI trends. Identifying factors that shape an individual's life-long BMI path after age 20 would be a fruitful topic for future research.

Third, this study confirms the finding of previous studies that in Japan children's BMI differs from that of adults (Yoshiike et al. 2002; Takimoto et al. 2004; Hermanussen et al. 2007; Funatogawa et al. 2008 and 2009; Sugawara et al. 2009; Kagawa and Hills 2011; Kagawa et al. 2011). An epidemiology study by Goldhaber-Fiebert et al. (2013) has also found a weak correlation between adult obesity and child obesity at the individual level. Further research is needed to examine the determinants of BMI trends in childhood and adulthood separately.

Fourth, existing hypotheses in the literature regarding the determinants of BMI trends cannot explain the striking gender difference in the BMI trend that we study in this paper. The persistent BMI decline among Japanese women suggests that economic growth does not necessarily accompany an increase in BMI. In fact, Japan has experienced almost all of the lifestyle changes that are considered to be factors contributing to the global obesity epidemic, such as an increase in the availability of high-calorie food, an increase in the opportunity cost of preparing healthful food, decreased energy consumption in regard to both work and leisure activities, and a decrease in the medical costs of obesity (Senauer and Gemma 2006).

What caused the shift in the female BMI trend from increasing to decreasing at the specific timing remains an open question. Here we briefly discuss possible causes. First, the diffusion of American popular culture and western clothes might have both influenced women's body image perceptions and increased men's preferences toward slim women. Second, women's physical attractiveness might have become more important in the marriage market, as love marriages increasingly took place of traditional arranged marriages and as visibility of women to men increased due to a rise in female labor participation and a sharp increase of coeducational schools. Third, the rise in female labor participation might have increased women's energy expenditure, provided that employment is associated with higher levels of physical activity than non-employment on average. Forth, biological factors, such as a sharp decrease in fertility and improved nutrition might be relevant, because maternal body weight is positively associated with parity (Siega-Riz et al. 2004) and because the association between perinatal nutritional restriction and obesity in adulthood is stronger among females than among males (Robinson 2012). However, none of these changes is unique to Japan, although the long-term decrease in adult female BMI appears to be a phenomenon unique to Japan. Future research that identifies factors underlying the declining BMI trend among Japanese women will provide invaluable information for designing effective policies to confront the obesity pandemic.

References

Arimatsu, Misao, Kitano, Takao, Kitano, Naoko, Futatsuka, Makoto, 2009. "Correlation between Bone Mineral Density and Body Composition in Japanese Females Aged 18–40 Years with Low Forearm Bone Mineral Density," *Environmental Health and Preventive Medicine*, 14(1): 46-51.

Bassino, Jean-Pascal, Kato, Noriko, 2010. "Rich and Slim, But Relatively Short: Explaining the Halt in the Secular Trend in Japan," Center for Economic Institutions Working Paper Series No. 2010-5, Hitotsubashi University, Institute of Economic Research.

Bielecki, Emily M., Haas, Jere D., Hulanicka, Barbara, 2012. “Secular Changes in the Height of Polish Schoolboys from 1955 to 1988,” *Economics & Human Biology*, 10(3): 310-317.

Cameron, A. Colin, and Trivedi, Pravin K, 2005. *Microeconometrics: Methods and Applications*, Cambridge University Press.

Cawley, John, 2010. “The Economics of Childhood Obesity.” *Health Affairs*, 29(3): 364-371.

Chisuwa, Naomi, O’Dea, Jennifer A., 2010. “Body Image and Eating Disorders amongst Japanese Adolescents: A Review of the Literature,” *Appetite*, 54: 5–15.

Costa, Dora, Steckel, Richard H., 1997. “Long-Term Trends in Health, Welfare, and Economic Growth in the United States,” In Steckel, Richard H., and Floud, Roderick, Eds. *Health and Welfare during Industrialization*, 47–90, University of Chicago Press.

Cutler, David M., Glaeser, Edward L., Shapiro, Jesse M., 2003. “Why Have Americans Become More Obese?” *Journal of Economic Perspectives*, 17(3), 93-118.

Davis, Ann M., Bennett, Kevin J., Befort, Christie, Nollen, Nikki. 2011. “Obesity and Related Health Behaviors among Urban and Rural Children in the United States: Data from the National Health and Nutrition Examination Survey 2003–2004 and 2005–2006.” *Journal of Pediatric Psychology*, 36(6): 669–676.

Finkelstein, Eric A., Strombotne, Kiersten L., 2010. “The Economics of Obesity.” *American Journal of Clinical Nutrition*, 91(5): 1520S-1524S.

Finucane, Mariel M., Stevens, Gretchen A., Cowan, Melanie J., Danaei, Goodarz, Lin, John K., Paciorek, Christopher J., Singh, Gitanjali M., Gutierrez, Hialy R., Lu, Yuan, Bahalim, Adil N., Farzadfar, Farshad, Riley, Leanne M., Ezzati, Majid,

2011. “National, Regional, and Global Trends in Body-Mass Index Since 1980: Systematic Analysis of Health Examination Surveys and Epidemiological Studies with 960 Country-Years and 9.1 Million Participants,” *Lancet*, 377: 557–67.

Floud, Roderick, Fogel, Robert W., Harris, Bernard, Hong, Sok Chul, 2011. *The Changing Body: Health, Nutrition, and Human Development in the Western World since 1700*. Cambridge: Cambridge University Press.

Funatogawa, Ikuko, Funatogawa, Takeshi, Yano, Eiji, 2008. “Do Overweight Children Necessarily Make Overweight Adults? Repeated Cross Sectional Annual Nationwide Survey of Japanese Girls and Women over Nearly Six Decades,” *British Medical Journal*, 337: a802.

Funatogawa, Ikuko, Funatogawa, Takeshi, Nakao, Mutsuhiro, Karita, Kanae, Yano, Eiji, 2009. “Changes in Body Mass Index by Birth Cohort in Japanese Adults: Results from the National Nutrition Survey of Japan 1956-2005,” *International Journal of Epidemiology*, 38(2): 83-92.

Goldhaber-Fiebert, Jeremy, Rubinfeld, Rachel, Bhattacharya, Jay, Robinson, Thomas N., Wise, Paul H., 2013. “Utility of Childhood and Adolescent Obesity Assessment in Relation to Adult Health,” *Medical Decision Making*, 33(2): 163-75.

Gorber, S. C., Tremblay, M., Moher, D. Gorber, B., 2007. “A Comparison of Direct vs. Self-report Measures for Assessing Height, Weight and Body Mass Index: A Systematic Review,” *Obesity Reviews*, 8(4): 307–326.

Goryakin, Yevgeniy, Suhrcke, Marc, 2014. “Economic Development, Urbanization, Technological Change and Overweight: What Do We Learn from 244 Demographic and Health Surveys?” *Economics and Human Biology*, 14: 109-127.

Harita, Nobuko, Kariya, Masatoshi, Hayashi, Tomoshige, Sato-Kogawa, Kyoko, Aoki, Takuya, Nakamura, Kimihiko, Endo, Ginji, Narimoto, Katsuhiko, 2012. "Gestational Bodyweight Gain among Underweight Japanese Women Related to Small-for-Gestational-Age Birth," *Journal of Obstetrics and Gynaecology Research*, 38(9): 1137–1144.

Health and Nutrition Study Group, 1998. *Nutritional Trends in Post-war Showa Era: An Overview of National Nutrition Survey in the Past 40 Years*, Tokyo: Daiichi Shuppan. (In Japanese)

Hermanussen, Michael, Molinari, Luciano, Satake, Takashi, 2007. "BMI in Japanese Children since 1948: No Evidence of a Major Rise in the Prevalence of Obesity in Japan," *Anthropologischer Anzeiger*, 65(3):275-283.

Hozawa, Atsushi, Okamura, Tomonori, Oki, Izumi, Murakami, Yoshitaka, Kadowaki, Takashi, Nakamura, Koshi, Miyamatsu, Naomi, Hayakawa, Takehito, Kita, Yoshikuni, Nakamura, Yosikazu, Nakamura, Yasuyuki, Abbott, Robert D., Okayama, Akira, Ueshima, Hirotsugu, 2008. "Relationship between BMI and All-cause Mortality in Japan: NIPPON DATA80," *Obesity*, 16(7): 1714–1717.

Johnson, William, Soloway, Laura E., Erickson, Darin, Choh, Audrey C., Lee, Miryoung, Chumlea, William C., Siervogel, Roger M., Czerwinski, Stefan A., Towne, Bradford, Demerath, Ellen W., 2012. "A Changing Pattern of Childhood BMI Growth during the 20th Century: 70 y of Data from the Fels Longitudinal Study," *American Journal of Clinical Nutrition*, 95(5): 1136–43.

Kagawa, Masaharu, Hills, Andrew P., 2011. "Secular Changes in BMI and Obesity Risk in Japanese Children: Considerations from a Morphologic Perspective." *The Open Obesity Journal*, 3: 9-6.

Kagawa, Masaharu, Tahara, Yasuaki, Moji, Kazuhiko, Nakao, Rieko, Aoyagi, Kiyoshi, Hills, Andrew P., 2011. "Secular Changes in Growth among Japanese Children Over 100 Years (1900-2000)" *Asia Pacific Journal of Clinical Nutrition*, 20(2): 180-189.

Katanoda, Kota, Nitta, Hiroshi, Hayashi, Kunihiko, Matsumura, Yasuhiro, 2005. "Is the National Nutrition Survey in Japan Representative of the Entire Japanese Population?" *Nutrition*, 21(9): 964–966.

Keyes, Katherine M., Utz, Rebecca L., Robinson, Whitney, Li, Guohua, 2010. "What Is a Cohort Effect? Comparison of Three Statistical Methods for Modeling Cohort Effects in Obesity Prevalence in the United States, 1971–2006", *Social Science & Medicine*, 70(7): 1100-1108.

Kikuchi, Joji, 1997. "Access to Selective Secondary Schools in Modern Japan: Reconsidered", *Departmental Bulletin Paper*. (in Japanese) http://hdl.handle.net/11094/3581

Komlos, John, Brabec, Marek, 2010. "The Trend of Mean BMI Values of US Adults, Birth Cohorts 1882–1986 Indicates that the Obesity Epidemic Began Earlier than Hitherto Thought," *American Journal of Human Biology*, 22(5): 631–638.

Komlos, John, Brabec, Marek, 2011. "The Trend of BMI Values of US Adults by Deciles, Birth Cohorts 1882–1986 Stratified by Gender and Ethnicity," *Economics & Human Biology*, 9(3): 234-250.

Komlos, John, Breitfelder, Ariane, Sunder, Marco, 2009. "The Transition to Post-Industrial BMI Values Among US Children," *American Journal of Human Biology*, 21: 151–160.

Kryst, Łukasz, Kowal, Małgorzata, Woronkowicz, Agnieszka, Sobiecki. Jan, Cichocka, Barbara Anna, 2012. “Secular Changes in Height, Body Weight, Body Mass Index and Pubertal Development in Male Children and Adolescents in Krakow, Poland,” *Journal of Biosocial Science*, 44(4): 495-507.

Kwon, Jin-Won, Song, Yun-mi, Sung, Joohon, Sohn, YeoJin, Cho, Sung-il, 2007. “Varying Patterns of BMI Increase in Sex and Birth Cohorts of Korean Adults,” *Obesity*, 15(2): 277-282.

Lahti-Koski, M., Jousilahti, P., Pietinen, P., 2001. “Secular Trends in Body Mass Index by Birth Cohort in Eastern Finland from 1972 to 1997.” *International Journal of Obesity*, 25(5): 727-734.

Lee, Hedwig, Lee, Dohoon, Guo, Guang, Harris, Kathleen Mullan, 2011. “Trends in Body Mass Index in Adolescence and Young Adulthood in the United States: 1959–2002,” *Journal of Adolescent Health*, 49: 601–608.

McKenzie, David J., 2006. “Disentangling Age, Cohort and Time Effects in the Additive Model,” *Oxford Bulletin of Economics and Statistics*, 68(4): 473-495.

Ministry of Education, 1980. *Japan's Modern Educational System: A History of the First Hundred Years.* Tokyo: Printing Bureau, Ministry of Finance. http://www.mext.go.jp/b_menu/hakusho/html/others/detail/1317220.htm

Ministry of Health, Labour and Welfare, 2013. *Overview of the National Health and Nutrition Survey of Year 2011*. (in Japanese)
http://www.mhlw.go.jp/stf/houdou/2r98520000020qbb.html
http://www.e-stat.go.jp/SG1/estat/List.do?bid=000001014499&cycode=0#TOP

Ministry of Welfare Research Institute, 1942. “Survey Report on the State of the Wartime Population's Nutritional Condition”, reprinted in Katsuyoshi Shimizu eds.

Top Secret Documents of the Fifteen-Year War vol. 21. Tokyo: Fuji Shuppan, 1990 (in Japanese).

http://www.ipss.go.jp/syoushika/tohkei/Popular/Popular2013.asp?chap=4&title1=%87W%81D%8Fo%90%B6%81E%89%C6%91%B0%8Cv%89%E6

National Women's Education Center of Japan, 2013. *Gender Statistics Database*. http://winet.nwec.jp/toukei/save/xls/L113020.xls

Ng, Marie, Fleming, Tom, Robinson, Margaret, et al., 2014. "Global, Regional, and National Prevalence of Overweight and Obesity in Children and Adults during 1980-2013: A Systematic Analysis for the Global Burden of Disease Study 2013," *Lancet*, forthcoming.

Núñez, Javier, Pérez, Graciela, 2014. "Trends in Physical Stature across Socioeconomic Groups of Chilean Boys, 1880-1997," *Economics & Human Biology*, forthcoming.

OECD, 2012. *Obesity Update 2012*. http://www.oecd.org/health/49716427.pdf

Patterson, Paul D., Moore, Charity G., Probst, Janice C., and Shinogle, Judith A., 2004. "Obesity and Physical Inactivity in Rural America," *The Journal of Rural Health*, 20(2): 151–159.

Petranović, Matea Zajc, Tomas, Željka, Narančić, Nina Smolej, Škarić-Jurić, Tatjana, Andrea Veček, Miličić, Jasna, 2014. "A Six Decades Long Follow-up on Body Size in Adolescents from Zagreb, Croatia (1951-2010)," *Economics & Human Biology*, 13: 155-164.

Prentice, Andrew M., 2006. "The Emerging Epidemic of Obesity in Developing Countries," *International Journal of Epidemiology*, 35 (1): 93-99.

Robinson, Whitney R., 2012. "Gender-Specific Effects of Early Nutritional Restriction on Adult Obesity Risk: Evidence from Quasi-Experimental Studies," *Obesity*, 20(12): 2464-2466.

Senauer, Benjamin, Gemma, Masahiko, 2006. "Reducing Obesity: What Americans Can Learn from the Japanese," *Choices*, 21(4): 265-268.

Siega-Riz, Anna Maria, Evenson, Kelly R., Dole, Nancy, 2004. "Pregnancy-related Weight Gain: A Link to Obesity?" *Nutrition Reviews*, 62(7): (II) S105–S111.

Sugawara A, Saito K, Sato M, Kodama S, Sone H, 2009. "Thinness in Japanese Young Women," *Epidemiology*, 20(3): 464-5.

Takimoto, Hidemi, Yoshiike, Nobuo, Kaneda, Fumi, Yoshita, Katsushi, 2004. "Thinness among Young Japanese Women," *American Journal of Public Health*, 94(9): 1592-1595.

Teikoku Life Insurance Company, 1946. "A Study on the Physique of Japanese People," *Journal of the Association of Insurance Medicine of Japan*, 44(1): 1-5 (in Japanese).

Vignerová, J, Brabec, M, Bláha, P, 2006. "Two Centuries of Growth among Czech Children and Youth," *Economics & Human Biology*, 4(2): 237-252.

Vignerová, J, Humeníkova, L, Brabec, M, Riedlová, J, Bláha, P, 2007. "Long-term Changes in Body Weight, BMI, and Adiposity Rebound among Children and Adolescents in the Czech Republic," *Economics & Human Biology*, 5(3): 409–425.

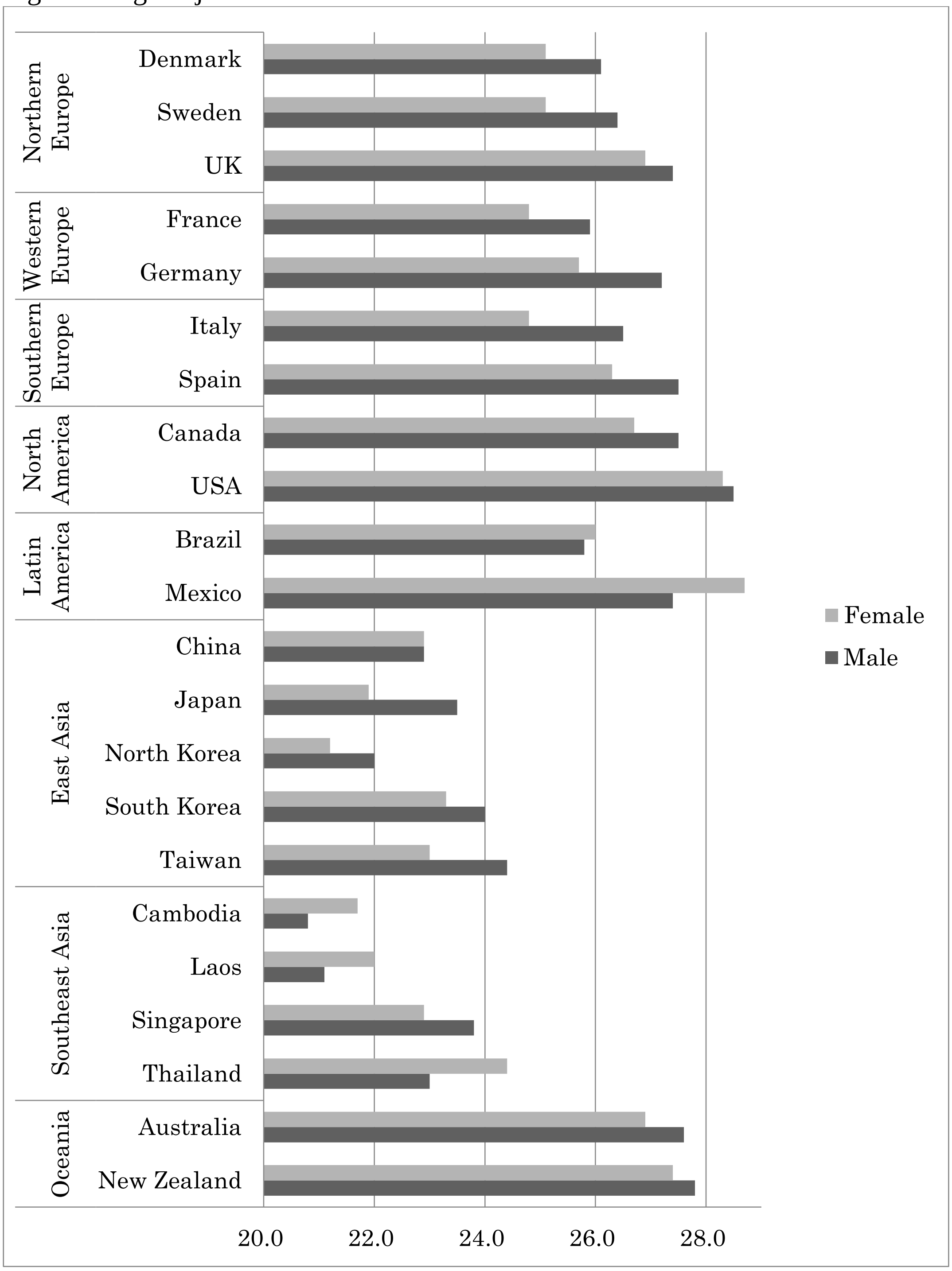
Yamamura, Eiji, 2012. "Influence of Body Image in Urbanized Areas: Differences in Long-term Changes in Teenage Body Mass Index between Boys and Girls in Japan," *Journal of Bioeconomics*, 14(3): 243-256.

Yoshiike, N, Seino, NF, Tajima, S, Arai, Y, Kawano, M, Furuhata, T, Inoue, S, 2002. "Twenty-Year Changes in the Prevalence of Overweight in Japanese Adults: The

National Nutrition Survey 1976–95," *Obesity Reviews*, 3(3): 183–190.

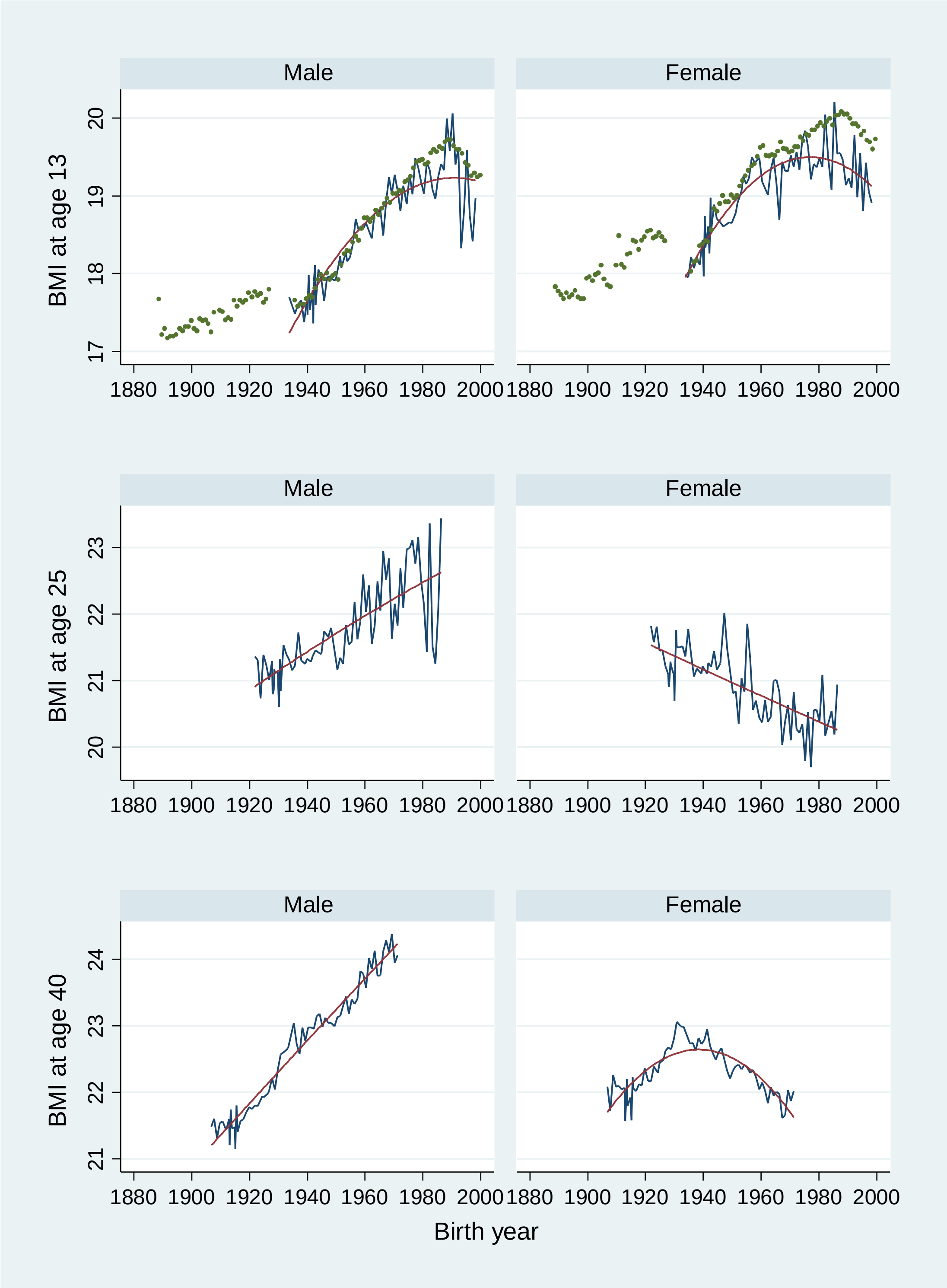
Zellner, Konrad, Ulbricht, Gottfried, Kromeyer-Hauschild, Katrin, 2007. "Long-term Trends in Body Mass Index of Children in Jena, Eastern Germany," *Economics & Human Biology*, 5(3): 426-434.

Figure 1: Age-adjusted BMI in 2008



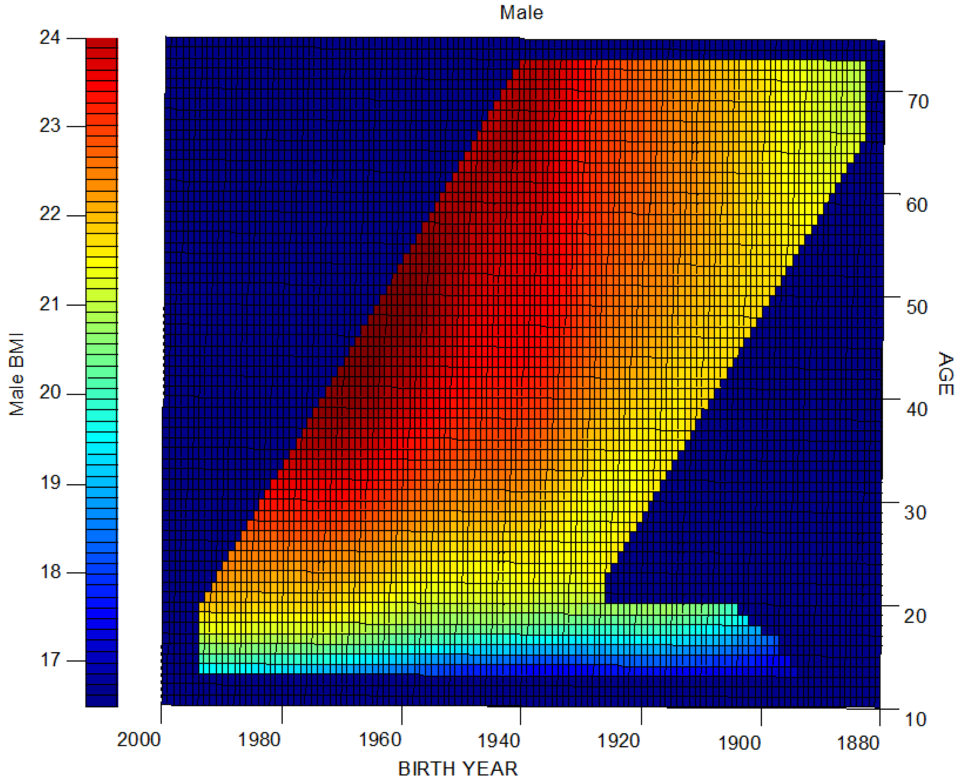
Source: Web appendix to Finucane et al. (2011).

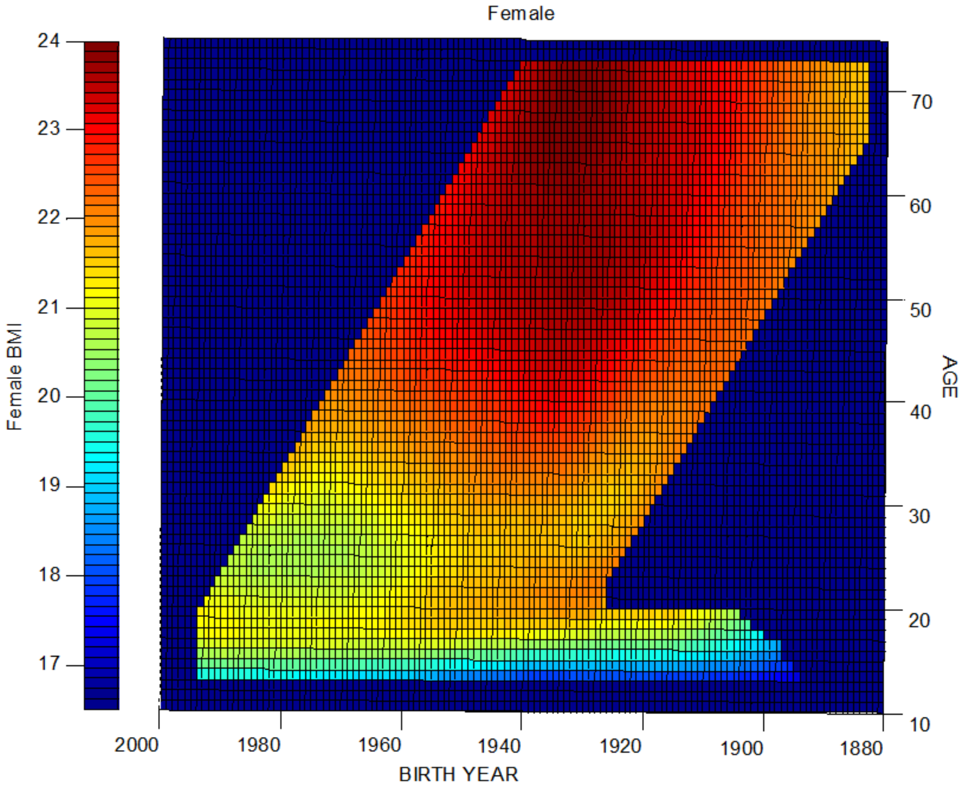
Figure 2: Age-Specific BMI by Sex and Birth Cohort –Ages 13, 25, and 40



Note: Blue lines represent the National Nutrition Survey (NNS) data. The School Health Survey (SHS) data are superimposed by green dots. In all six panels, red fitted lines are based on quadratic regression. The point estimate of the turning point for female BMI at age 40 is 1937.0.

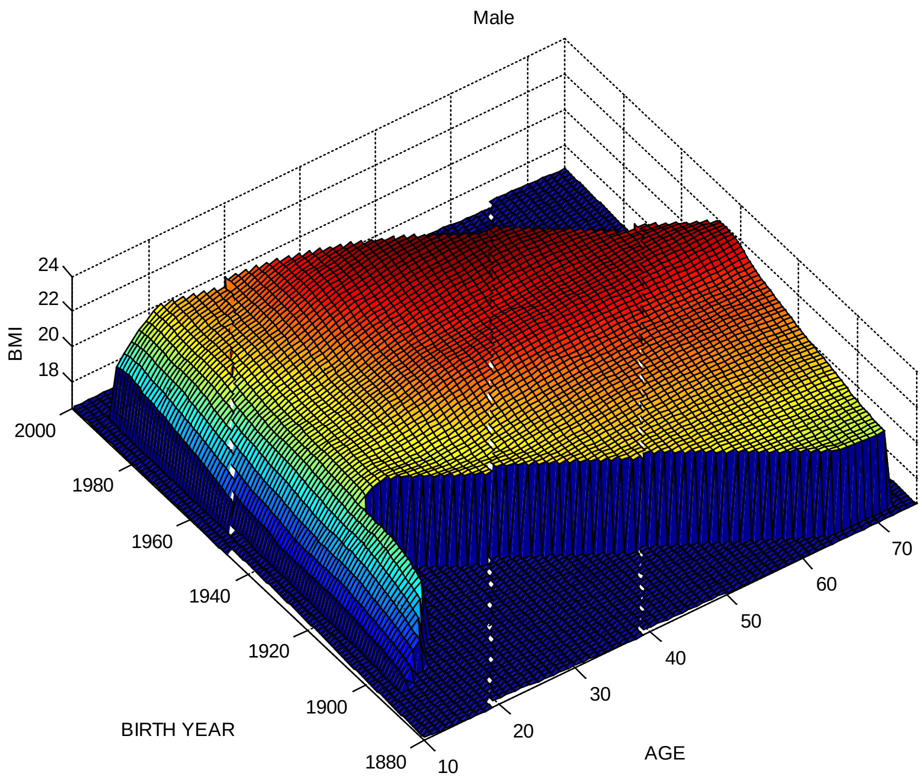
Figure 3: BMI by Age and Birth Cohort Based on Locally Weighted Regression
Figure 3 – (a)





Note: Dark blue indicates the area where fitted BMI was not generated.

Figure 3 – (b)



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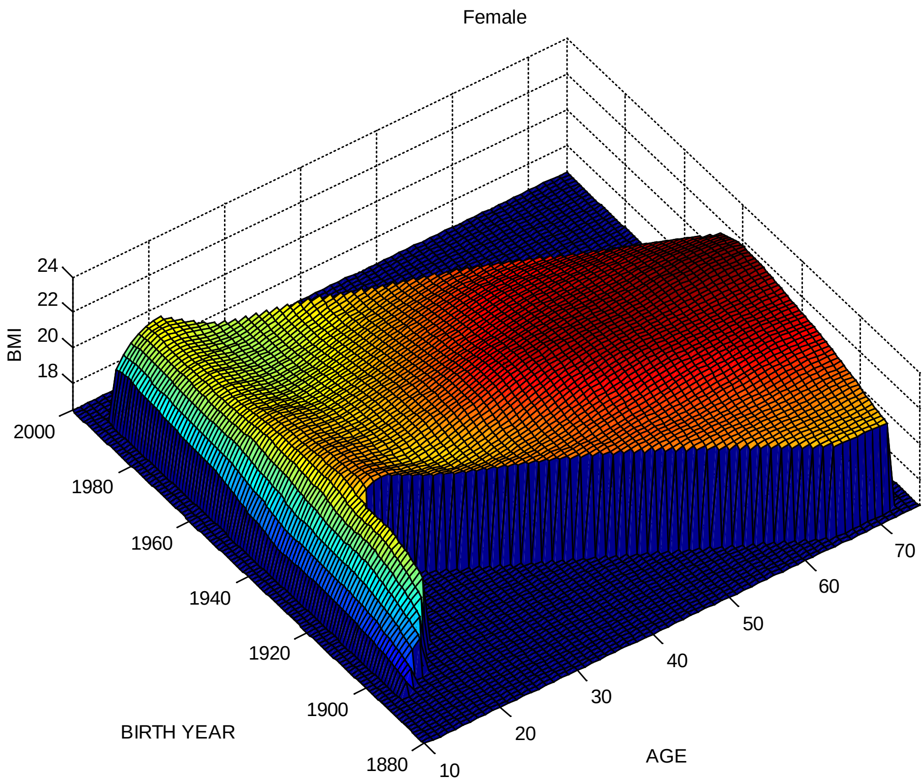
AGE



Female
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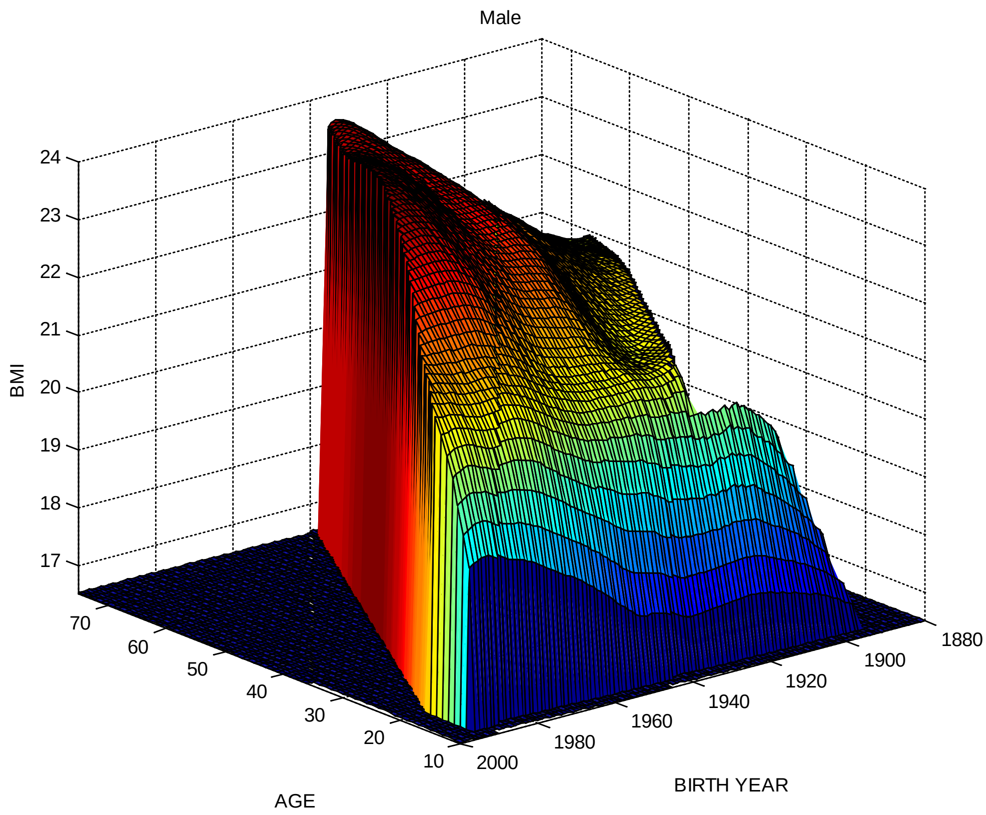
AGE

Figure 3 – (c)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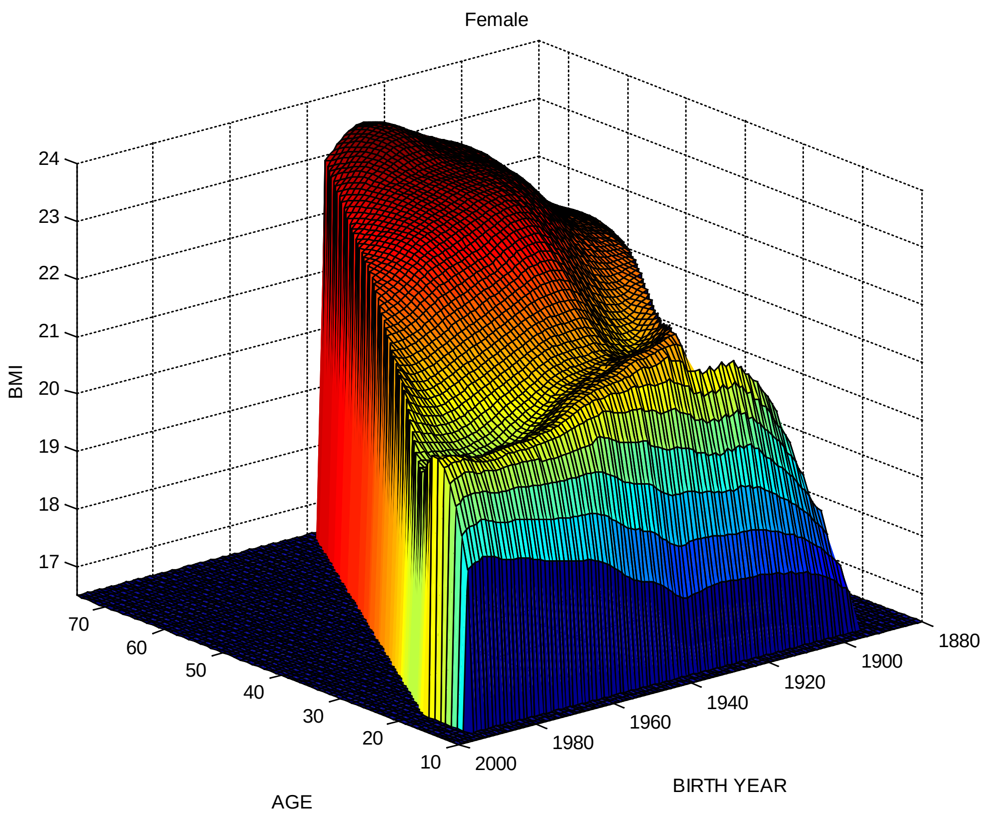
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Figure 4: Height by Age and Birth Cohort Based on Locally Weighted Regression

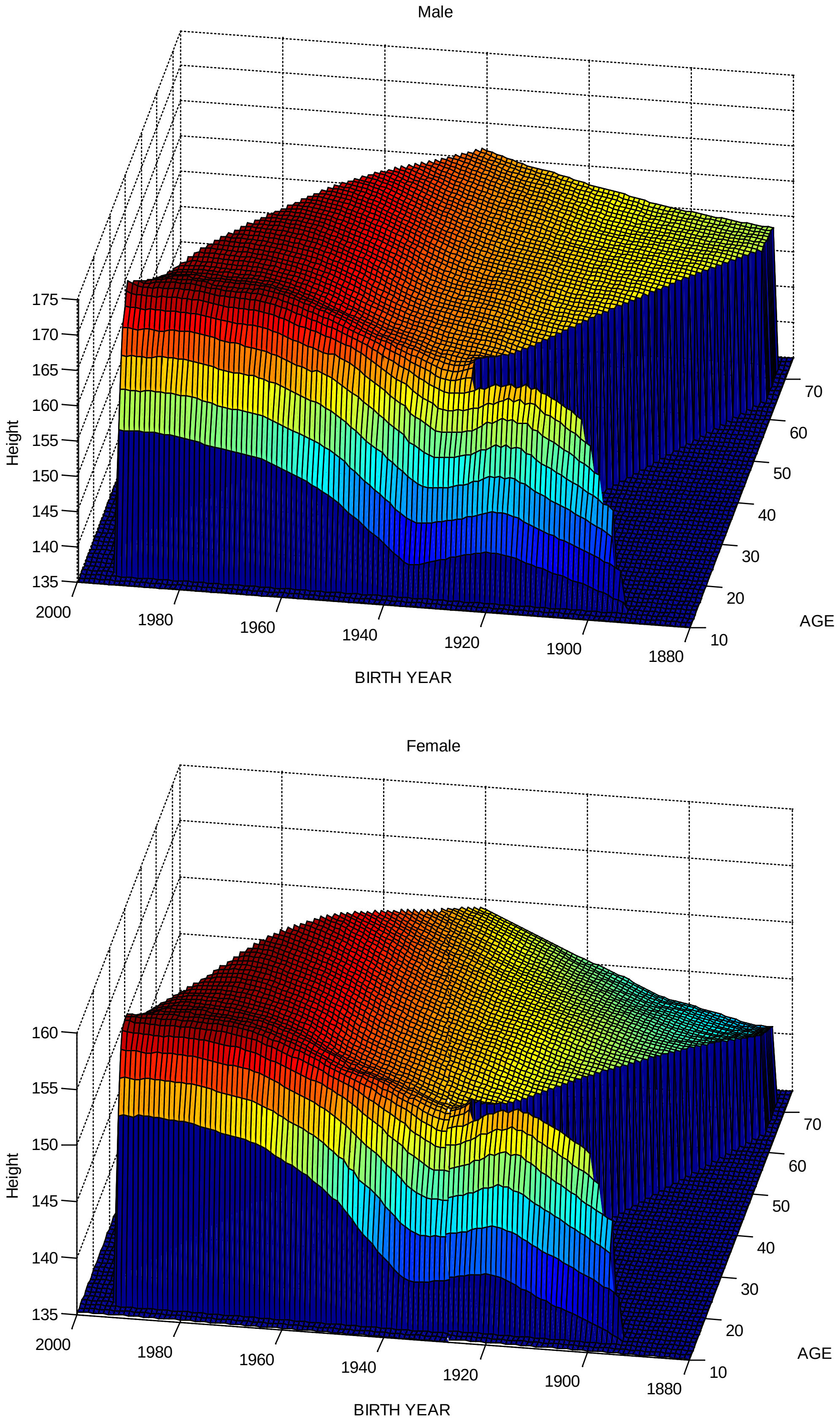
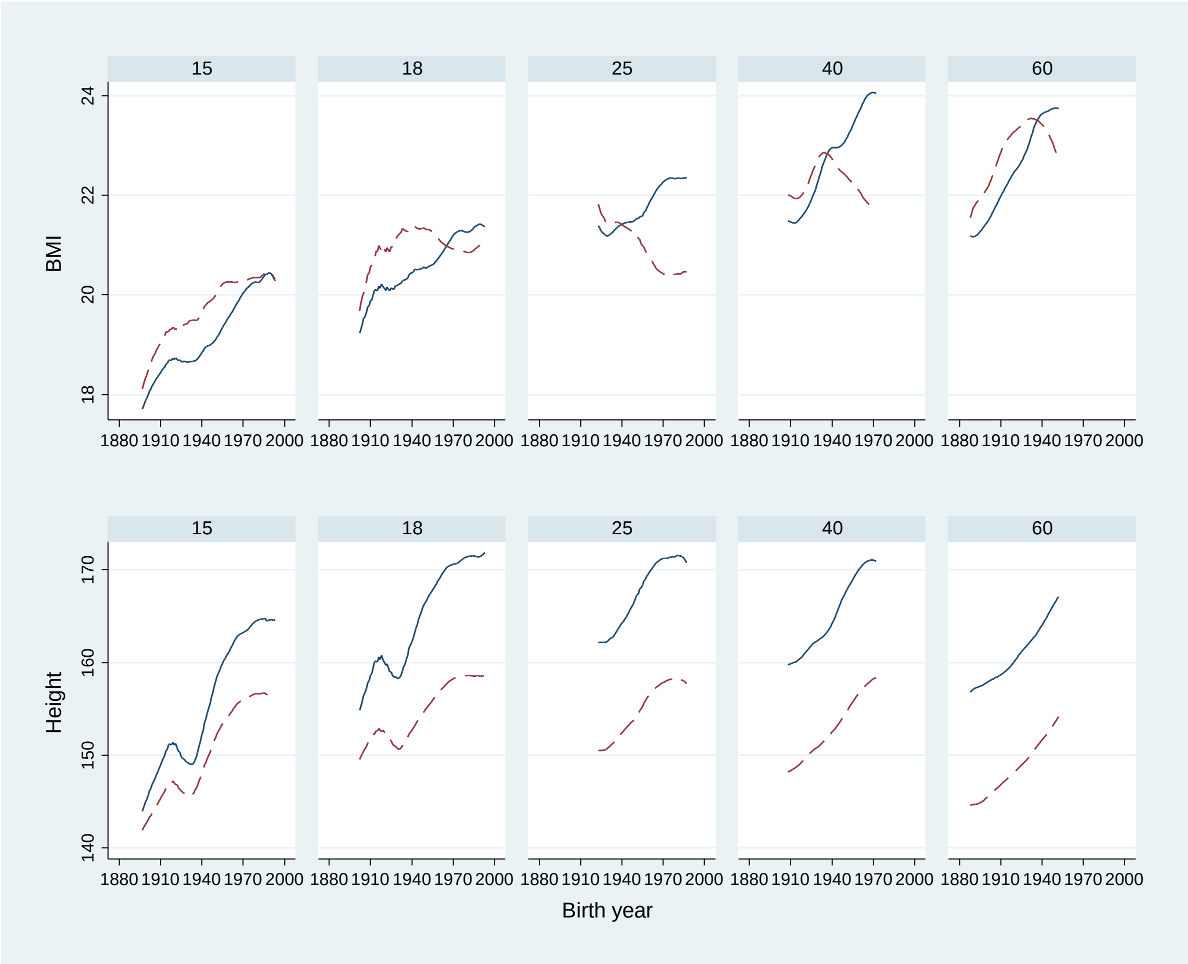


Figure 5: Age-Specific BMI and Height Based on Locally Weighted Regression– Ages 15, 18, 25, 40, and 60



Note: Blue solid lines represent males and red dashed lines represent females.