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Abstract

Short Abstract

The age-specific body mass index (BMI) of adult Japanese women has steadily decreased over time, while that of Japanese men has increased. This study examines the long-term trend of age-specific BMI in Japan, by combining unique historical data sets and conducting nonparametric regression analysis. We find that the decline in female BMI is a cohort-specific phenomenon with women born in the 1930s having the highest BMI. However, the age-specific BMI of young girls has continuously increased throughout the 20th century. We conclude that the BMI decline can be traced back to females in their late teen years shortly after WWII. (100 words)

Long Abstract

The Japanese feature body mass index (BMI) significantly lower than those in other high-income countries, and the thinness of Japanese women is particularly prominent. Moreover, the age-specific BMI of adult Japanese women has steadily decreased over time, in contrast to the consistent increase in that of Japanese men. This study examines the long-term trend of age-specific BMI in Japan, by combining a couple of the world's best historical data on height and weight in terms of the sample representativeness, accuracy, and length of the time period covered. We investigate not only *when* the BMI decline among women started, but also *how*, that is, whether it started as a period-specific phenomenon or as a cohort-specific phenomenon. To address the highly nonlinear nature of BMI trends, we conduct nonparametric regression analysis. Our analysis yields three clear results. First, the BMI decline in female is a cohort-specific phenomenon with women born in the 1930s having the highest BMI. Second, girls up to their early teen years do not follow this cohort trend. Indeed, their age-specific BMIs have continuously increased throughout the 20th century. Third, the height of males and females follows a similar growing trend, implying that the gender difference in the BMI trend results from the difference in the trend of weight. We conclude that the BMI decline can be traced back to females in their late teen years shortly after WWII. (230 words)

Highlights

- We study the long-term trend of age-specific BMI in Japan in the 20th century.
- We use unique historical data sets and conduct nonparametric regression analysis.
- BMI increased for adult men and decreased for adult women in postwar Japan.
- The BMI decline among adult women is cohort-specific and not period-specific.
- The age-specific BMI of children grew steadily for both sexes in the 20th century.

JEL codes: C14; I10; N35

Keywords: Body Mass Index, Underweight, Cohort analysis, Secular trends, Japan, Locally Weighted Regression

1. Introduction

Men and women are rapidly gaining body weight in most parts of the world – a phenomenon called the global obesity pandemic. Conventional explanations for this trend include the availability of high-calorie food, the higher opportunity costs of preparing healthy food, decreased energy consumption at work due to automation and motorization, and decreased costs for obesity due to medical progress (Cutler et al. 2003; Cawley 2010; Finkelstein and Strombotne 2010). In sharp contrast to this global trend, however, the Japanese have a significantly lower obesity rate and body mass index (BMI, henceforce, which is defined as (weight in kilograms) divided by (height in meters)^2), than in other high-income countries, and the thinness of Japanese women is particularly prominent (Finucane et al. 2011; OECD 2012). Even more curiously, while the age-specific BMI shows a steady increase for Japanese men, a *decreasing* trend is observed for adult Japanese women over several decades (Takimoto et al. 2004; Funatogawa et al. 2008 and 2009; Sugawara et al. 2009). The conventional explanations cannot rationalize this gender difference in BMI trends in Japan.

The aim of this paper is to identify *when* and *how* this decline in BMI among Japanese women started, based on a more suitable methodological framework and more detailed data work than earlier studies. Regarding the first question, *when*, it is unlikely that the BMI of Japanese women has decreased throughout the history. The literature has found that a higher national income tends to be associated with a higher average BMI both cross-sectionally and longitudinally (Finucane et al. 2011; Floud et al. 2011). Instead, it would be natural to presume that there exists a certain turning point in the past when the current declining trend started. In addition to *when*, we also examine *how*, that is, whether Japanese women in all ages started becoming thinner at some point of time (a period-specific phenomenon) or the BMI decline started with a particular cohort (a cohort-specific phenomenon). Answering these questions provides insights for the mechanism underlying long-term macro BMI trends in modern societies.

This study combines two historical data sources: (1) National Nutrition Survey (NNS) for the years 1947-2011 and (2) School Health Survey (SHS) for the years 1901-2012. Both NNS and SHS provide height and weight data measured by professional nurses, and these are among the best historical data on height and weight in the world in terms of the sample representativeness, accuracy, and length of the time period covered. The combination of NNS and SHS provides a comprehensive picture of Japanese BMI trends. Because BMI trends in Japan are highly non-linear, we conduct a non-parametric locally weighted regression to delineate the origin of the BMI decline among Japanese women. The locally weighted regression approach has an advantage in illustrating the BMI trend as precisely as possible right after WWII, a period in which only limited data is available. We also examine to what extent changes in height and weight account for the changes in BMI.

Our analysis yields three clear results. First, the decline in BMI among Japanese women is a cohort-specific phenomenon with women born in the 1930s having the highest BMI. It is highly unlikely that women of all ages started to become thinner at the same time. This is in sharp contrast to a drop in BMI due to the food shortage during WWII and its aftermath, which is period-specific and experienced by both males and females of all ages. Second, girls up to their early teen years do not follow this cohort trend. Indeed, their age-specific BMIs have continuously increased throughout the 20th century. Third, the height of both males and females follows a growing trend, implying that the gender difference in the BMI trends should be attributed to trends in weight rather than height. In summary, the BMI decline can be traced back to females in their late teen years shortly after WWII.

2. Related Studies

A host of empirical evidence indicates that Japan offers important research material for advancing BMI and obesity research, because of its unique position in terms of both the level and trend of BMI. Comparing recent age-adjusted adult BMIs across 199 countries, Finucane et al. (2011) show that Japanese males have the lowest BMI among high-income countries and that female BMI in Japan is not only among the lowest in high-income countries but also rather close to BMI in low-income countries such as Cambodia, Laos, and North Korea (Figure 1).[1] Eating disorders are not driving these trends, as its prevalence in Japan remains significantly lower than in Western countries (Chisuwa and O'Dea 2010), contrary to the common belief that attributes low body weight in developed countries to the consequence of eating disorders.

[1] In 2011, the prevalence of underweight (BMI below 18.5) was 11.0% among adult Japanese women and 29.0% among Japanese women in their twenties (Ministry of Health, Labor and Welfare 2013). Underweight is becoming a public health issue in Japan because it is associated with higher mortality and with health conditions such as low bone mineral density and small-for-gestational-age deliveries (Hozawa et al. 2008; Arimatsu et al. 2009; Harita et al. 2012).

Not only the level but also the decline in BMI places Japanese women in a unique position in the worldwide trend of the global obesity pandemic. Finucane et al. (2011) review BMI trends in the 199 countries from 1980 to 2008, and show that Japan is one of the nineteen countries where age-adjusted female BMI has not increased significantly. There is a paucity of cohort studies that cover a longer period based on population-representative data, but there are a few studies in the U.S. that find growth in BMI for both sexes at all age levels since 1959 (Komlos et al. 2009; Komlos and Brabec 2010; Lee et al. 2011).[2] Vignerová et al. (2007) conduct a cohort study based on the population-representative data of Czech children from 1951 to 2001, and they find that the median BMI of late-teen Czech girls significantly decreased, while that of boys remained almost constant. These gender-specific BMI trends in the Czech Republic are somewhat similar to those in Japan, but Japan and the Czech Republic have immensely different histories as the Czech Republic was under communist rule from 1948 to 1989.

Previous Japanese studies on BMI are based on either NNS or SHS (but not both) and all concern specific age groups, and the majority of them focus on children and adolescents. Studies on child BMI mostly use SHS and find increasing trends (Hermanussen et al. 2007; Kagawa et al. 2011; Kagawa and Hills 2011). Kagawa et al. (2011), covering the longest time period among these studies, analyze BMI trends among schoolchildren throughout the 20th century using SHS and find a continuous increase for both boys and girls. In contrast, studies on young women, typically in their late teen years and 20s, find decreasing BMI trends over several decades based on NNS (Takimoto et al. 2004; Sugawara et al. 2009). Funatogawa et al. (2008) study the BMI

[2] These studies disagree over when the rapid BMI growth started.

trend of both small girls and young females using NNS from 1948 to 2005, and conclude that more recent cohorts have higher BMIs as children and lower BMIs in early adulthood. Regarding the long-term BMI trends of adults, Funatogawa et al. (2009) use NNS from 1956 to 2005 and regress BMI on age groups, birth-cohort groups, and their interaction terms, and they find the importance of the cohort effect.

This study advances the literature in three ways. First, we include data on adult BMI shortly after WWII for the first time. The early years of NNS (years from 1947 to 1955) are indispensable for tracing the origin of BMI trends. Funatogawa et al. (2009) also analyze BMI trends of Japanese adults, but they only use NNS from 1956.[3] Average body weights in NNS are not directly comparable before and after 1956 because pregnant women were excluded only after 1956. To address this potential problem, we adjust for maternity weight gains.[4] Second, this study combines SHS and NNS for the

[3] While Funatogawa et al. (2009) argue that their results demonstrate strong cohort effects and the age-specific female BMIs peaked at the 1931-1940 cohort, these conclusions are derived essentially from the extrapolated BMIs for the early 1950s based on their linearity assumptions that both age effects and cohort effects are time-invariant and that the age-cohort effect is constant throughout the 1950s. These assumptions, however, do not align with previous findings that the effects of age and cohort are highly nonlinear and time-variable among young women (Funatogawa et al. 2008; Sugawara et al. 2009). Their results for the later years merely indicate that cohorts born in the 1920s and 1930s were the peak cohorts when they are in their 50s and 60s.

[4] Funatogawa et al. (2008) use NNS before 1956 to study females of 25 years old and younger but do not account for this potential problem.

first time in the literature. While SHS only covers schoolchildren, it offers important implications for adult BMI trends before WWII. In particular, SHS enables us to delineate long-term BMI trends among adolescents during the first half of the 20th century and to compare BMI trends between boys and girls. Third, we address potential selection bias in SHS for the first time in the literature. Fourth, we employ an estimation method that allows us to address the highly nonlinear relationship 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 the aggregation of BMI measures by rough age and cohort groups of five to ten year intervals, which prevent them from the precise description of BMI trends, especially around the war period. The nonparametric method we employ also allows us to fully utilize data around the time of WWII.

3. Data

Our sample is derived from NNS and SHS. These data sources provide the means of height and weight by age and birth year. By sex, age, and cohort, the “mean” BMI is constructed by dividing mean weight (in kilograms) by the square of mean height (in meters). This section briefly outlines these data sources and our definition of the cohort. Further details on the construction of the data set are provided in Appendix 1. We also include two small-scale data sources that provide prewar adult stature data (the Conscription Examination Data and Teikoku Life Insurance Data), although we find their limited contributions to our main results. These data sources are also described in Appendix 2.

3.1. National Nutrition Survey (NNS)

NNS provides nationally representative data of height and weight for the Japanese one year old and older since shortly after WWII.[5] NNS was renamed as National Health and Nutrition Survey (NHNS) in 2003, but we refer to both NNS and NHNS as NNS throughout this paper. Similar surveys exist for other countries but started later than NNS. 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 started in 1959. American conscript-based data provide information on the height and weight of soldiers in the mid-19th century and are highly representative of the population, but the coverage is limited to young men (Costa and Steckel 1997).

NNS was initiated in December 1945 by the government under the command of the General Headquarters Supreme Commander for the Allied Power (GHQ/SCAP) with its aim to assess the nutritional status of the Japanese suffering from severe food shortage after WWII. Initially NNS only covered the Tokyo Metropolitan area, but the coverage was increased in a few years to cover all Japanese prefectures since 1948. We use NNS data from 1947 to 2011, because height was added to NNS in 1947 and NNS coverage was expanded to 29 out of 46 Japanese prefectures.[6] Sample size varies greatly by

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[5] Katanoda and Matsumura (2002) provide detailed explanation of NNS.

[6] The number of prefectures increased to 47 in 1972 when Okinawa was returned to Japan. NNS covers the Okinawa prefecture since 1972.

survey year. In 1948, the sample size was about 39,000 individuals of 6,200 households. By the mid-1960s, the sample size was increased to about 68,000 individuals of 16,500 households. Then, the sample size was gradually reduced to 6,900 individuals of 3,400 households in 2011. The response rate is not reported at the individual-level, but in 2011, for instance, 58% of the households invited to the survey participated in the survey. Katanoda et al. (2005) confirm the national representativeness of NNS.

We use mean height and weight reported in either annual reports of NNS or a reproduction report by Health and Nutrition Study Group (1998).[7] Height and weight are measured without shoes by health professionals with adjustment for the weight of clothes, and thus they are quite accurate and free from reporting bias associated with self-reports (Gorber et al. 2007). Height and weight are assessed four times per year until 1955 and annually since 1956.[8] We use data from all four assessments only for 1953 and 1955 due to data availability.

Means of height and weight are reported by age for 1-25 years olds and by age groups for the older age. Age groups beyond 25 are by decades in most survey years but slightly differ across survey years. We use cubic spline to recover mean height and

[7] In a very few cases, the numbers in the original reports and the reproduced numbers disagree. Because these discrepancies are apparently due to mistypes, we have employed the more plausible numbers.

[8] Since 1956, weight and height were measured in May for years 1956-1963, 1965, and 1967-1971 and in November for the other years except for 1974 when body measurements were not conducted.

weight for each age older than 25 years based on the data of those 24 years old or older, assuming that the reported mean value for an age group equals the mean value at the midpoint age of the age group bracket. Thus the mean height of the age group 30-39, for instance, is regarded as the mean height for age 34.5. Because the oldest age bracket does not have a midpoint, we calculate the mean age of the oldest age bracket for each sex using the Population Census from the closest year.[9]

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

3.2. School Health Survey (SHS)

SHS started in 1900 as a nationally representative survey of Japanese school children. We know of no other similar data covering such a long time period. SHS is based on the annual body measurements of pupils that all schools in Japan have been legally required to record under the School Health and Safety Act.[10] Every year between April and June,

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[9] In the spline estimation, we take the average of the mean values for 24 and 25 year olds and regard it as the mean value for 24.5 year olds to smooth out the relatively large variation in the mean values by age due to the small number of observations in each age.

[10] After WWII, "schools" refer to kindergartens, elementary schools, and junior and senior high schools. Before WWII, "schools" include kindergartens, ordinary and higher elementary schools, boys' middle schools, girls' high schools, and vocational schools.

school nurses measure the height and weight of children without their shoes and in light clothes. Hence, reporting errors are minimal. Since 1900, SHS has been conducted by the Ministry of Education, Science, Culture and Sports (formerly the Ministry of Education). Based on a randomly extracted sample of schools, it provides nationally representative data on height and weight for school children aged 6-17 since 1900, except for 1921 and 1940-1947. From 1948, the mean height and weight of kindergarten children in the senior class (age 5-6) were added to the survey.[11] The sample size is large. In 2012, for example, 695,600 pupils of 7,755 schools are included, corresponding to 4.9% of the population of pupils. Mean height and weight by age and sex are available in the Statistical Report of the SHS (Ministry of Internal Affairs and Communications 2013). Because the age-grade system has been strictly enforced since the amendment of Elementary School Law in 1900, almost all children in Japan start school at the same age. In addition, repeating or skipping grades have been quite rare in Japan. Thus SHS provides an excellent data source for studying BMI trends.

On the other hand, because SHS is limited to pupils attending a school, selection bias is naturally a concern. However, our view is that such bias, if it exists, is quite small, because the school attendance rate in Japan has been quite high among industrialized countries since the early 20th century.[12] To minimize selection problems, we exclude

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[11] Except for the years 1952 and 1953.

[12] Japanese compulsory education started in 1886. In 1900 the attendance rate for the four years of compulsory education for children aged 6-10 years old reached 91% for boys and 72% for girls. In 1907, despite the extension of compulsory education from four to six years, the overall attendance rate reached 97% (Ministry of Education 1980).

groups of children with low school attendance rates by age and year. The details of this sample exclusion are provided in Appendix 1.

While SHS was not publicized during the war time, a hand-written report on nutritional status was compiled by researchers at the Ministry of Welfare in 1942 (Ministry of Welfare Research Institute 1942)[13]. From this report, we obtain the mean height and weight of elementary school children in the senior class (age 11-12). In October 1942, 550 elementary schools nationwide were asked to report the height and weight of children in the senior class, and 400 of them sent reports. The reported mean weight was based on the full sample of 37,998 children from these 400 schools and mean height was based on a subsample of children from 200 of the 400 schools.

3.3. Defining the Cohort

SHS is based on body measurements conducted around May, while the weight and height information of NNS is based on measurements in May or November, depending

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The attendance rate for non-compulsory middle school also rapidly increased during the early 20th century, and in 1936, 92% of boys and 80% of girls had additional formal schooling of two years or more beyond compulsory education (Kikuchi 1997). In 1947, compulsory education was extended to nine years, from ages 6 through 15, and the school attendance rate for compulsory education has always been above 99% since 1948. Additionally, 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).

[13] The confidential report was found and reprinted in 1990.

on the survey year. Thus we need to define the cohort in a consistent way across different survey timings. For example, consider a group of individuals reported as 20 years old in the NNS 1980 survey. If the survey was conducted on November 1st, this group would include individuals born between November 1959 and October 1960. We regard this group as the “May 1960 cohort” whose “aggregate birth year” is defined as 1960.33 because the midpoint birthday is the first of May 1960 (and hence 1960+120/365). Cohorts are defined analogously for other survey years and months. In SHS, age groups are based on grades, and the grade in Japan is determined by the age at April 1st. Hence, for instance, a group of children reported as ten years old in the May 1980 SHS includes children who were born between April 2nd 1969 and April 1st 1970.[14] We regard this group as the “October 1969 cohort” whose aggregate birth year is 1969.75.

Another non-standard feature of SHS is that, while age groups in SHS are based on grades, i.e. the age on April 1st, the body measurements are conducted later around May. This time lag creates another discrepancy between NNS and SHS. In the regression analysis below, we take into account this discrepancy by re-defining age. The details of this age adjustment are provided in Appendix 1.

4. Analysis

4.1. Age specific BMI by cohorts

Before turning to non-parametric analysis, we discuss the descriptive characteristics of the two data sets. Figure 2(a) presents the mean BMI at age 13 by sex and birth year.

[14] Under Japanese law individuals become one year older one day before the birthday.

The blue lines plot values calculated using NNS and the red lines are the fitted curves for the plotted NNS values based on a quadratic least-squares regression. The green dots represent the BMI values based on SHS. The SHS values are slightly larger than the NNS values, but this is as expected because the timing of measurement relative to age is slightly later in SHS. We adjust this time gap between NNS and SHS when we conduct regression analysis below. NNS values fluctuate more than SHS values due to the smaller sample size of NNS compared to that of SHS. Thus combining SHS with NNS enhances precision in the analysis of children's BMI. Overall, NNS and SHS show highly consistent patterns, suggesting the accuracy and representativeness of both data sources. The figure indicates that the mean BMI for thirteen-year olds consistently increased over the last 100 years for both boys and girls, except for the sharp drop around the 1930 cohort and the decline in cohorts born in the 1990s. The 1930 cohort was thirteen years old in 1943 and suffering from a severe food shortage around the war period.

Figure 2(b) presents the mean BMI at age 18 based on NNS and shows different trends between males and females. While male BMI kept increasing since WWII (i.e., from the 1929 cohorts), female BMI steadily decreased, at least for the first fifty years. The mean BMI at age 25 presented in Figure 2(c) shows a similar but even greater gender difference. Figure 2(d) shows the mean BMI at age 40, which exhibits an inverse U-shaped pattern in female BMI with a peak at cohorts born in the 1930s. The red fitted quadratic curve for female BMI peaked at the 1938 cohort. In contrast, male BMI steadily increased over the last sixty years. Highly similar patterns to these are found for both sexes in the mean BMI at age 60 presented in Figure 2(e). Female BMI features an inverse U-shape, and the quadratic regression indicates that females born in 1932 have the largest BMI.

Although the limited space prevents us from showing the graphs for all ages, the results for the other ages are largely consistent with those described above. We summarize the trends in age-specific BMI as follows. First, up to the early teen years, age-specific BMI increased throughout the 20th century for both sexes, except for noticeable decreases among those born in around the 1930s and 90s. Second, in the older age, the patterns differed greatly by gender. While male BMI at any age monotonically increased over time, age-specific female BMI exhibited an inverse U-shaped pattern over time with the peak found around the cohorts born in the 1930. Therefore, the decline in the BMI of Japanese women involves only adult females, not early teen girls or younger. Third, the declining trend in BMI is cohort-specific and not period-specific. Age-specific BMI after age 30 consistently shows that female cohorts born in the 1930s have the highest BMI compared to both younger and older cohorts.

A remaining question is whether the age-specific BMI at the younger age (age 18 to 30) also peaked around the 1930s cohorts. We cannot directly observe this because there is no data around the war period. We nevertheless argue that cohorts born in the 1930s represent the turning point for age-specific female BMI not only after age 30 but also at ages between 18 and 30 for the following reasons. First, the age-specific BMI of women in this age category shows a steady decrease after the 1930s cohort. Second, the age-specific female BMI in the early teen years and 30 years old or older shows a constant increase up to the cohorts born in the 1930s. This fact makes it unlikely that the BMI at around age 20 was decreasing over decades of cohorts before the 1930s cohort.

4.2. Non-parametric Regression

The aim of the regression analysis is to describe how Japanese BMI changed with age and cohort in a more comprehensive way, and, in particular, to delineate the turning point of the BMI trend of Japanese females. The highly non-linear nature of the BMI trend is informative in understanding how the long-term decline in BMI among Japanese women started. Because such a non-linear trend may not be fully captured by simple parametric forms, we regress BMI on age and cohort non-parametrically.

We employ a locally weighted cubic regression of BMI on two regressors – birth year and age. A local regression estimator has a significant advantage compared to standard kernel estimators in avoiding boundary bias, that is, a flatter slope of regression estimator near the largest and smallest values of regressors. Although our sample is among the longest, it has limited coverage around WWII, meaning that there are many end points along the regressors. Because illustrating the BMI trend right 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 potentially highly complex movement of BMI across age and cohort, we employ a cubic functional form rather than a linear or quadratic form.

The regression analysis is implemented as follows. As is often the case with nonparametric analysis, we make somewhat arbitrary choices over model specifications so that the estimated BMI trend is sufficiently smooth but still maintains relevant movements in data. Denote the local regression estimator of BMI as $bmi(x, z)$, where the two regressors, x and z, represent birth year and age. 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 set of integer grid points that range from birth year 1883 to 1993 and from age 13 to 72. We do not report the estimated BMI for all of these integer grid points, because of the concern for potentially large bias due to extrapolation. Specifically, a regression estimator is reported only for integer grid points that have at least one observation within the distance of 1, with the following two exceptions. First, the child BMI during the war period is reported even if there is no observation within the distance of 1 because we have a considerable amount of information in *both* pre- and after-war periods, which allows us to reasonably estimate BMI as interpolation rather than as extrapolation. Second, we do not report the fitted BMI in the neighbor of a few pre-war data points constructed from the Teikoku Life Insurance Data. While the Teikoku Life Insurance Data assists non-parametric regression in obtaining fitted BMI in other parts, it provides too few observations to reliably estimate the BMI trend of pre-war adults.

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

$$\sum_{i=1}^{N} K\left(\frac{d}{h}\right)\begin{pmatrix} bmi_i - a - b_{1,0}\overline{x_\iota} - b_{0,1}\overline{z_\iota} - b_{2,0}\overline{x_\iota}^2 - b_{0,2}\overline{z_\iota}^2 - b_{1,1}\overline{x_\iota}\overline{z_\iota} \\ -b_{3,0}\overline{x_\iota}^3 - b_{0,3}\overline{z_\iota}^3 - b_{2,1}\overline{x_\iota}^2\overline{z_\iota} - b_{1,2}\overline{x_\iota}\overline{z_\iota}^2 \end{pmatrix}^2,$$

where $\overline{x_i}$ and $\overline{z_i}$ are $(x_i - x_0)$ and $(z_i - z_0)$, respectively, and *K*(.) is a kernel weighting function with distance $d = \sqrt{\overline{x_i}^2 + \overline{z_i}^2}$ and bandwidth h. *K*(.) gives a non-zero weight for the 600 nearest observations regardless of data sources. 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.

The estimated BMI trend is shown in Figures 3(a) to 3(c). All the graphs show the fitted BMI by sex conditional on birth year and age. The Y axis represents age and the X axis represents the birth year. 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) shows the graph seen from the above. The colored shapes in Figure 3(a) indicate the areas in the (birth year, age) space in which we report a regression estimator of BMI. We do not attempt to construct fitted BMI in the area in which we do not have sufficient data, except for child BMI during WWII.

Figure 3(b) shows the graphs seen from an oblique angle to highlight gender differences. The graphs in Figures 3(a) and 3(b) all visually highlight and reinforce our findings so far. Male BMI is monotonically increasing in both age and birth year, whereas female BMI is highly nonlinear in both age and birth year. 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 before it resumes monotonic increase after the late 20s. The finding that the mean BMI increases with age for both boys and girls up to the early teen years is consistent with previous studies (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 among Korean women (Kwon et al. 2007), though studies in Finland and the U.S. report monotonic increase in BMI with age for both sexes (Jacobsen 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 on 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 cohorts, while child BMI grows steadily with birth year for both males and females, adult female BMI features 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-20’s is a recent phenomenon, the root of the declining BMI trend dates as far back as women born in the 1930s.

Figure 3(c) shows the graphs seen from a further lower oblique angle. These graphs facilitate the comparison of the BMI trends of children and adults. As discussed above, the age-specific BMI of children increases with the birth year throughout the 20th century showing little gender difference, highlighting that the BMI decline only concerns females who are in their late teen years or older.

Figure 3(c) also illustrates an additional finding – the war effect. For both males and females, a hollow runs on the upper right of the graph, corresponding to a drop in BMI during the first couple of years after NNS started. This hollow runs diagonally (not vertically) in the (birth year, age) space, and it is observed similarly for both males and females, including children. This observation indicates that this plummet in BMI is not cohort-specific but year-specific, most likely reflecting the effect of WWII. Food shortages started during WWII (Ministry of Welfare Research Institute 1942) and continued through the early 1950s (Health and Nutrition Study Group 1998). This war effect provides a good contrast with the BMI decline among females, which is a cohort phenomenon concerning women born after 1930, with younger cohorts being thinner than older cohorts. In addition, the magnitude of the war effect is far smaller than that of the decades-lasting declining BMI trend among Japanese women.

4.3. Age specific height by cohorts

Because BMI is calculated based on height and weight, a change in BMI can be decomposed to changes in height and weight. Figure 4 presents the fitted mean height conditional on age and cohort by sex. The two graphs in Figure 4 indicate steady growth in height throughout the 20th century, except for the sharp drop around WWII and the recent slow-down, consistent with previous studies (Hermanussen et al. 2007; Funatogawa et al. 2009; Bassino and Kato 2010; Kagawa et al. 2011). This trend in height over cohorts is observed for both men and women, a pattern quite different from the trend in BMI. This implies that the decline in BMI among Japanese women in the late 20th century is caused by changes in weight, not by changes in height.[15]

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[15] The graphs clearly indicate the negative effect of WWII on children's height. We refrain from discussing the war effect in detail because data limitations prevent us from measuring the magnitude or duration of the effect precisely.

5. Conclusion

In this paper, we investigate when and how the BMI decline among Japanese women started. We combine two historical data sources, which are among the best historical data on height and weight in the world. A non-parametric regression analysis shows that the BMI decline can be traced back to females in their late teen years shortly after WWII.

Our study makes four additional important points to the large literature on BMI and obesity. First, highly nonlinear BMI trends exist even at the aggregated macro level in the long term. This fact highlights the importance of long-term data and calls for analytical frameworks that can address nonlinearity. Our estimation results indicate that simple parametric regression analysis with year, cohort, and year-cohort dummies used in the existing studies can produce misleading results.

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

Third, this study confirms different trends in BMI for children and adults in Japan, consistent with previous studies (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). This finding of distinct trends of children and adults is consistent with a weak correlation between adult obesity and child obesity at the individual level found in an epidemiology study (Goldhaber-Fiebert et al. 2013). Further studies are needed to examine the determinants of BMI trends in childhood and adulthood separately.

Fourth, existing hypotheses in the literature on the determinants of BMI cannot explain the striking gender difference in the BMI trend 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 changes in lifestyle that are considered as contributing factors to obesity growth, such as the availability of high-calorie food, increases in the opportunity costs of preparing healthy food, decreased energy consumption at work, and decreased costs for obesity due to medical progress, albeit to a lesser degree for some of them (Senauer and Gemma 2006). Identifying factors underlying the declining BMI trend among Japanese women might provide invaluable information for designing effective policies to confront the obesity pandemic.

This study broadens the perspective of obesity and BMI research by describing the long-term BMI trends in Japan that is beyond the scope of the existing literature. The cause of the BMI trend in Japan remains an open question.

Appendices

Appendix 1. Details of Data Construction

This appendix describes the construction of the main data set from NNS and SHS in more detail.

Sample exclusion criteria for SHS

We prepare the SHS data for our analysis as follows. We do not use data collected in 1900 because the body weight is only reported in kilograms without decimals and thus we cannot construct an accurate BMI measure. For years before WWII, children 17 years old or older are excluded because in this period most secondary education ended by the age of 16 or earlier and thus students aged 17 were a small minority. To further reduce the concern about selection bias, we also exclude older children from our pre-war sample taking account of the rapid increase in school enrolment and attendance rates in the early 20th century. Specifically, we limit our sample to children 11 years old and younger for 1906 and earlier years, children 13 years old and younger for 1907-10, children 15 years old and younger for years 1911-1919,[16] children 16 years old and younger for years 1920-1942, and children of all ages for 1948 and onward. We also attempt further limiting our sample to children in compulsory education, and find that it does not affect our conclusion.

Adjustments for Pregnancy Weight Gain

The average weight increase of pregnant women in 11 to 40 gestational weeks is calculated using data on biweekly maternal weight gain measured in 1981 as reported in Nakamura (1997). We use the oldest data available because maternal weight gain has been declining since the 1980s (Nakamura 1997 and 2003). We do not include earlier gestational weeks because maternal weight gain is negligible (less than 50 grams)

[16] The minimum term of study for girls' high schools was extended to five years in 1920.

before week 11, and because many women in early pregnancy might not be aware of their pregnancy, especially before home pregnancy test kits became commonly available in the 1990s. Assuming the average delivery weeks of 40 based on the oldest available Japanese data (Akama 1983; Nakamura 1997), the average maternal weight gain of women in gestation week 11-40 is estimated to be 5,939.3 grams.

Age-specific fertility rates in each year are constructed based on the fertility rate reported in National Institute of Population and Social Security Research (2013). Because the fertility rate is reported by five-year age groups, we use cubic spline to construct age-specific fertility rates by the same method used with NNS, assuming that the fertility rate is zero for women aged 15 and younger and those aged 55 or older. Similarly, as the fertility rate is only reported in 1947, 1950, and every five years since 1950, we impute age-specific fertility rates for years in between applying a linear interpolation to the two available years. Because the average weight gain during pregnancy is constructed by taking the average of weight increase over 30 weeks from the 11th to 40th gestational weeks, the proportion of women having the pregnancy weight gain among women sampled at one point of time is obtained as the fertility rate times 210/365. Thus the adjusted average weight is obtained by:

$$Adjusted = (Unadjusted - 5.9393) * (p*210/365) + Unadjusted*(1- p*210/365),$$

where *Adjusted* is the adjusted mean weight, *Unadjusted* is the reported raw mean weight, and *p* is the age-specific fertility rate. We have confirmed that our conclusions are not significantly affected by this adjustment.

Age Adjustments

Schools are legally required to conduct body measurements between April and June every year, but the school grade in Japan is based on the age as at April 1st. Because this time lag in SHS does not occur in NNS, we make an adjustment for the age so that we can analyze NNS and SHS in a coherent framework. Because SHS does not have the information on the actual date of measurement at each school, we assume that the measurement is conducted at the end of April. We re-define the height and weight at age x reported in NNS as those at age x+0.5, and re-define the height and weight at age x reported in SHS as at age x+0.5+30/365. For instance, the weight and height reported for the individuals who were 20 years old in the November 1980 NNS survey are regarded as the weight and height of cohorts born in 1960.33 at the age of 20.5. This adjustment for SHS is necessary because, although age determines which grade a child is in, the children whose birthday falls before the day of measurement are effectively one year older than their classmates.

Appendix 2. Two Additional Data Sources

NNS and SHS provide no information on adult stature in the prewar period. To address this insufficiency, we add to our sample two more data sources: (1) Conscription Examination Data for the years 1926 to 1932 and (2) body measurement data of life insurance applicants collected by Teikoku Life Insurance Company (henceforth Teikoku Life Insurance Data) for 1931. From these two data sets, we estimate "mean" BMI by sex, age, and cohort, and include them in our sample. These two prewar data sources assist the nonparametric estimation by stabilizing the results around WWII. However, we find that our main results are mostly unaffected by the inclusion of these prewar data sources, probably because they only provide a partial and incomplete supplement to the lack of data on adult stature before WWII.

Conscription Examination Data

Conscription examination was compulsory for all Japanese men at the age of 20 until the end of WWII, and was conducted nationwide annually between April and July. The Conscription Examination Data provides the population average of the height and weight of twenty-year-old men. We use the average height and weight recorded from 1926 to 1932 reported in Kaetsu (1934). We do not use data from 1912 to 1925 because weights were recorded in an old Japanese metric system (*Shakkanho*) until 1925, which is significantly less precise than the International System of Units. The age in the Conscription Examination Data is adjusted in the same way as the SHS data.

Teikoku Life Insurance Data

Teikoku Life Insurance Company required the height and weight of their life insurance applicants from 1927 to 1935 at the point of application, and the average by age and sex is reported in Teikoku Life Insurance Company (1946). The population is the life insurance applicants, and individuals aged 10-60 were eligible for the application. The sample size is 103,870 for men and 28,981 for women. Because the report provides only the average over the nine years rather than annual figures, we regard this data as mean heights and weights in 1931. Because the averages are aggregated by age group of five years for individuals aged 26 or older, we use cubic spline to estimate mean values for each age, the same method used with NNS. Likewise, we make adjustments for the inclusion of pregnant women using the fertility rate in 1930 in the same way used for NNS. Sample selection is clearly a problem with this data set. Compared to similar body measurement data on life insurance holders, the expected size of selection bias is smaller because this data source includes applicants regardless of the insurance acceptance status. Nevertheless, applications for life insurance are likely to correlate with income level. To address the selection problem, we limit our sample to individuals aged 10 to 30. Young applicants are likely to be the dependents of their parents, so their health and earning ability are unlikely to directly relate to the decision to apply for life insurance. In fact, the height and weight of applicant children aged 10 to 16 are reasonably close to their counterparts in SHS. While the selection problem could be more serious for individuals in their 20s, the variance in weight within the cohort is small in the 20s, thereby implying limited effects of selection bias. The height and weight of male applicants aged 20 are close to those in Conscription Examination Data, with applicants being slightly taller and heavier with a lower BMI. We make no age adjustments for Teikoku Life Insurance Data because the age in this data is reported based on insurance age.

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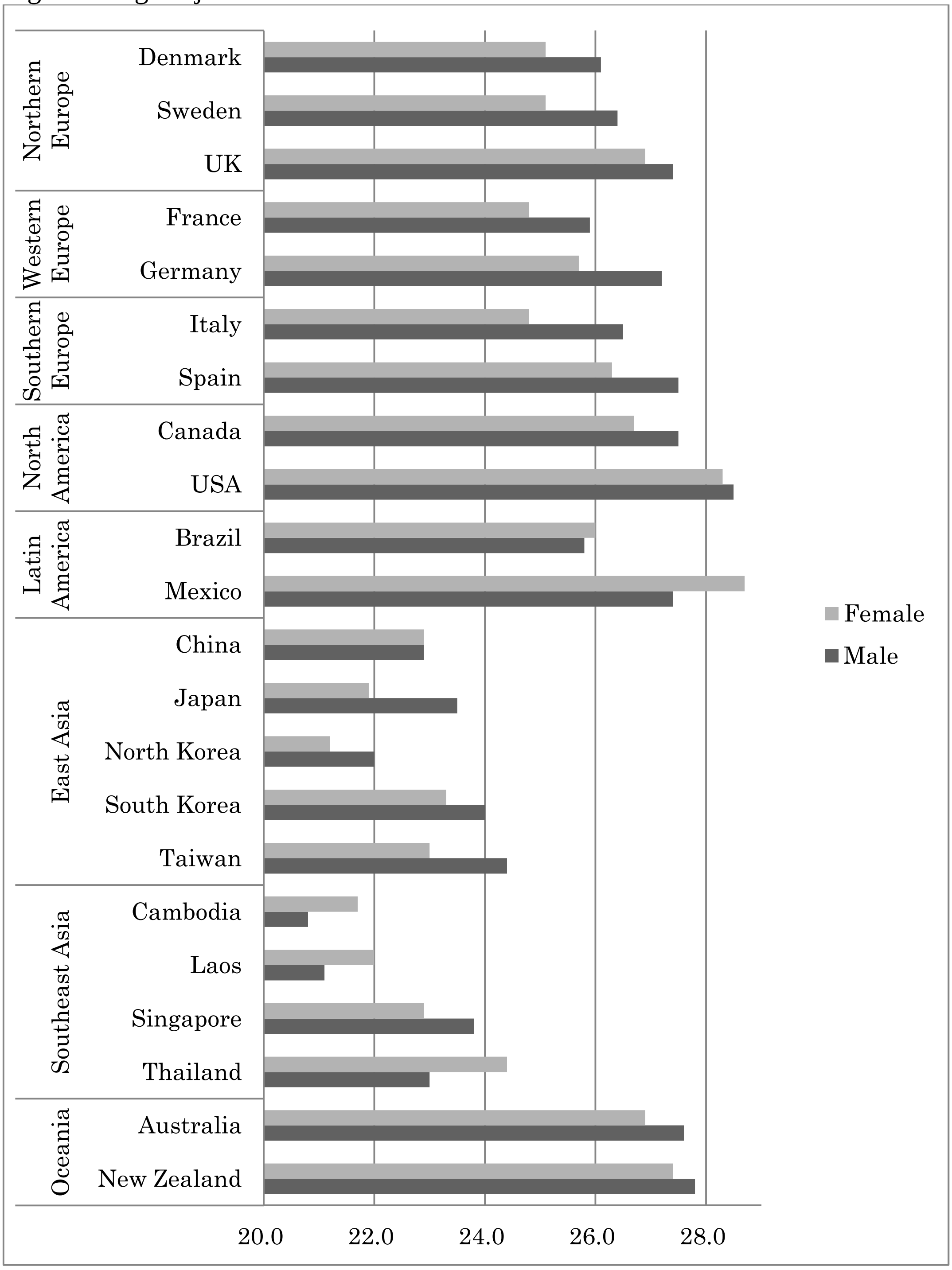
Figure 1: Age adjusted BMI in 2008



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

Figure 2: Age-Specific BMI by Sex and Cohort – At Selected Ages

Figure 2 – (a): Age 13

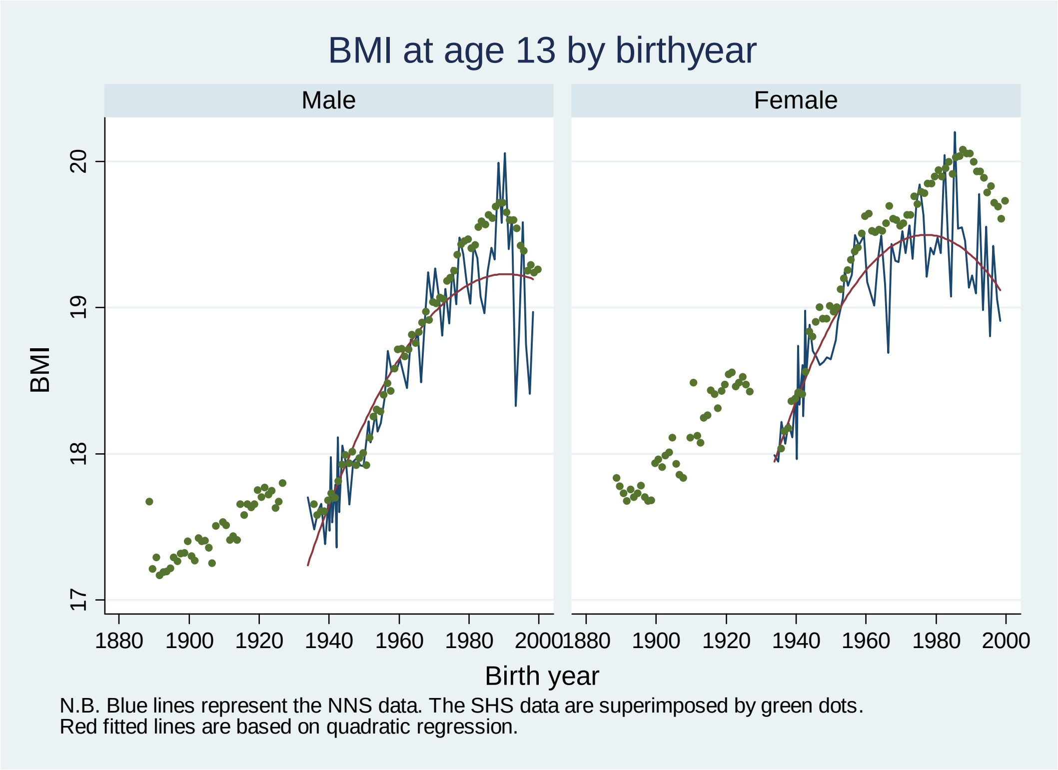


Figure 2 – (b): Age 18

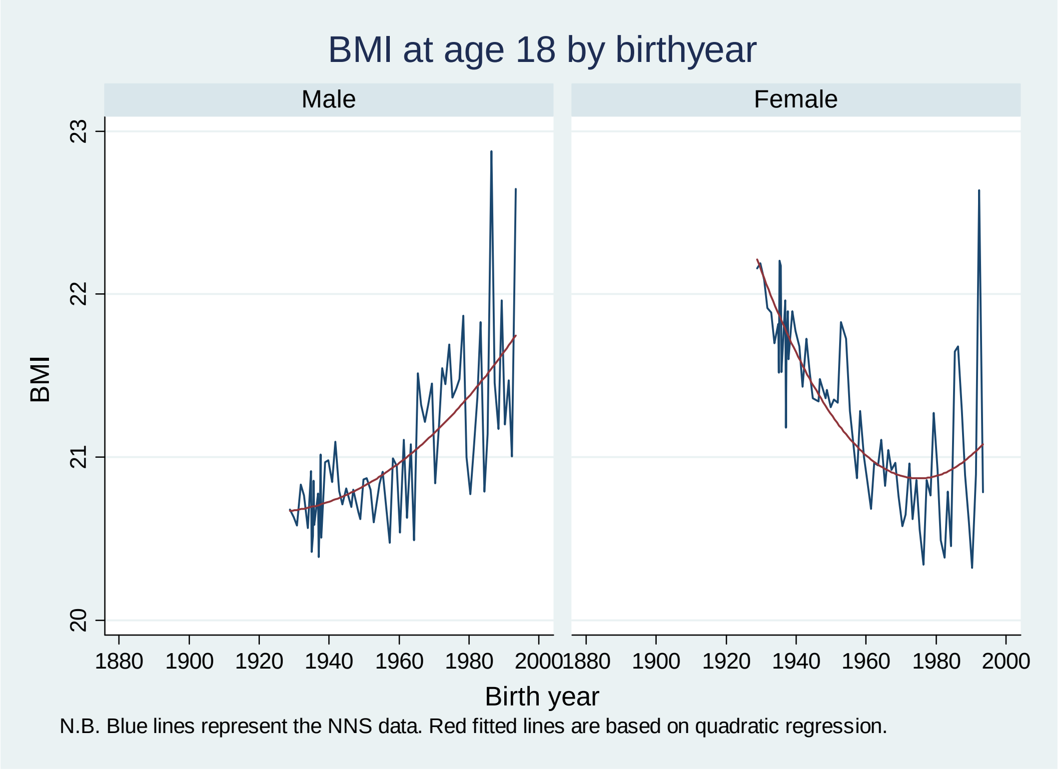


Figure 2 – (c): Age 25

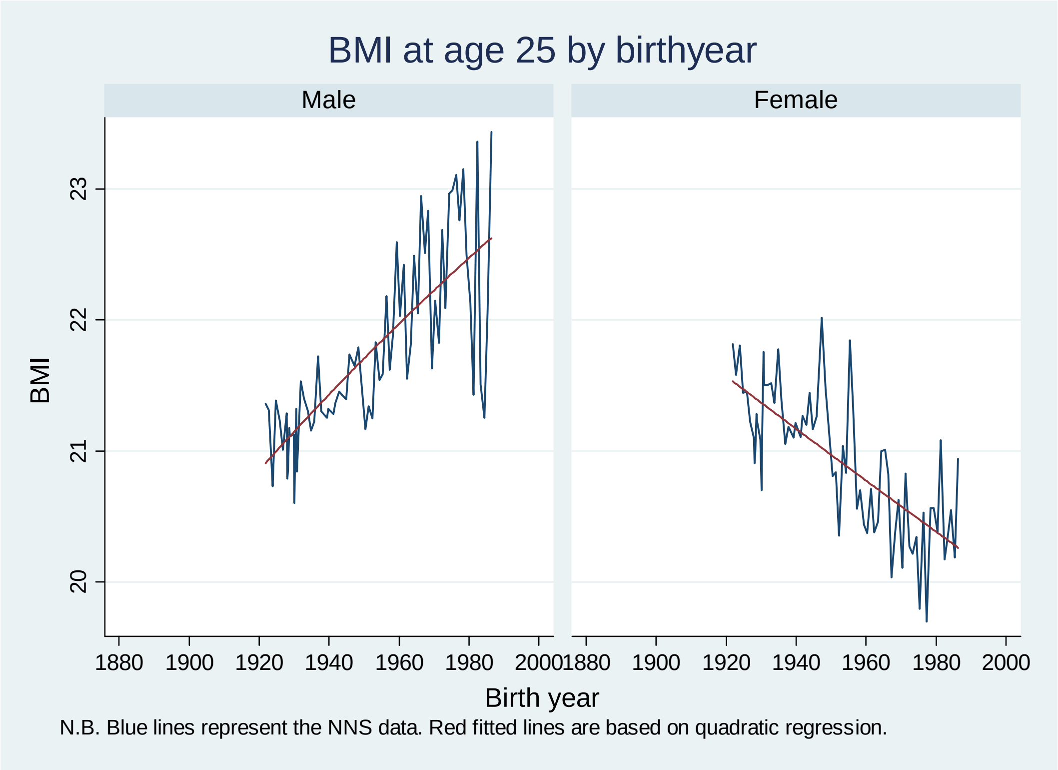


Figure 2 – (d): Age 40

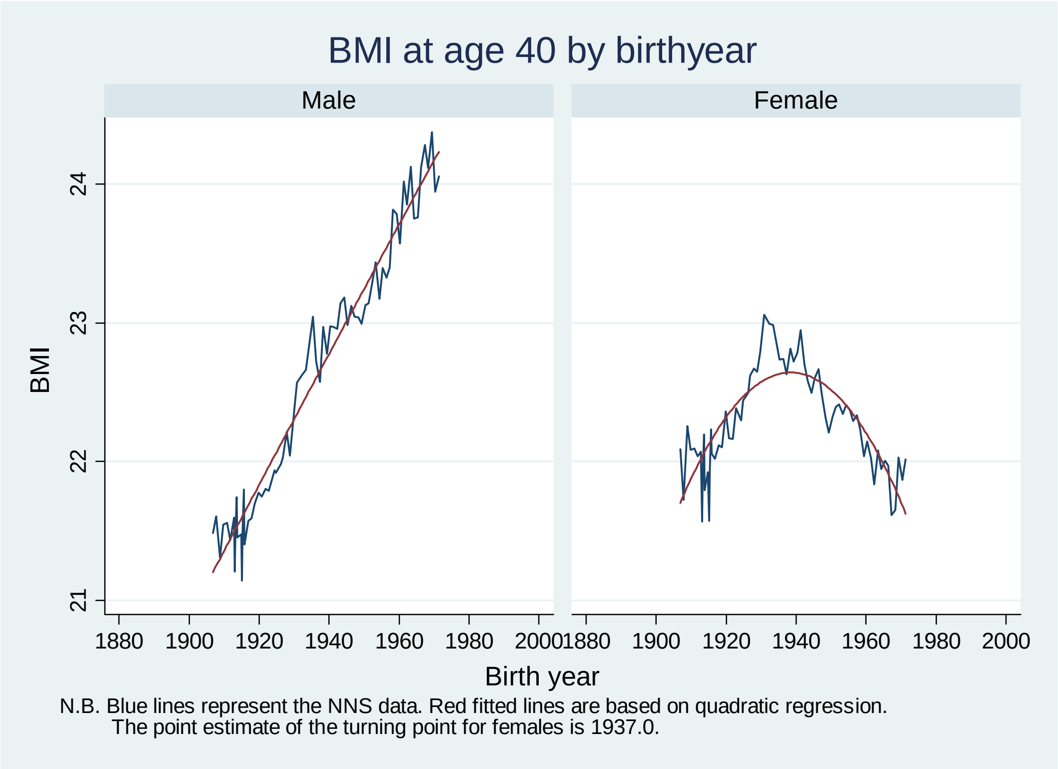


Figure 2 – (e): Age 60

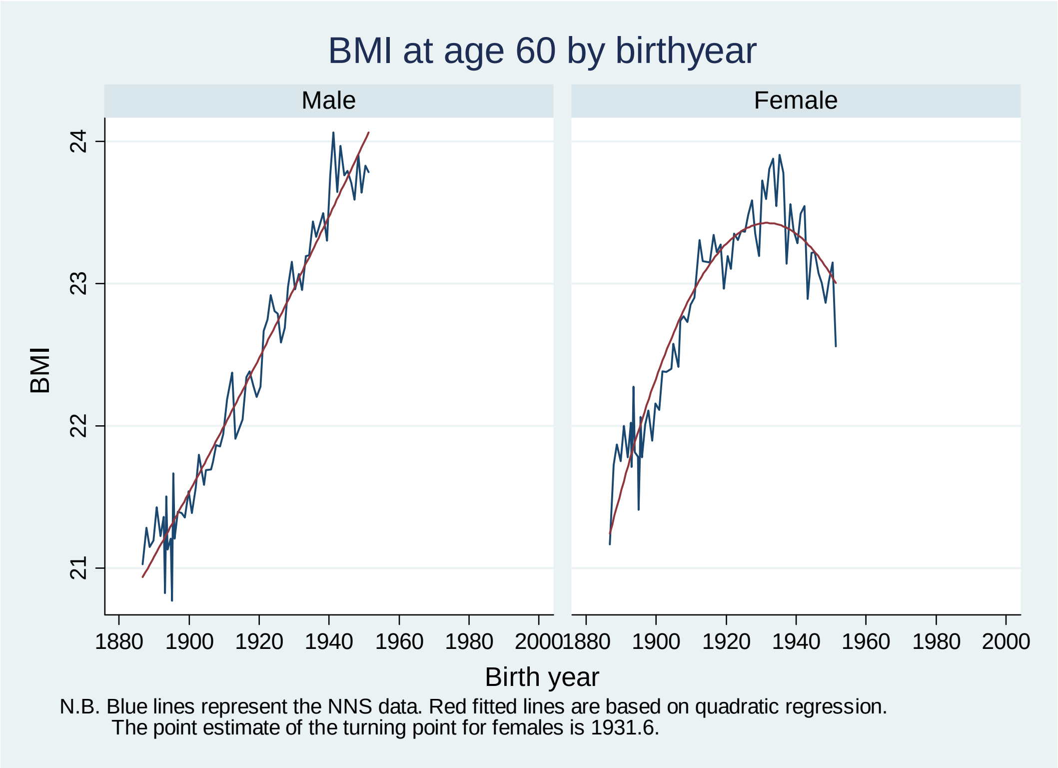
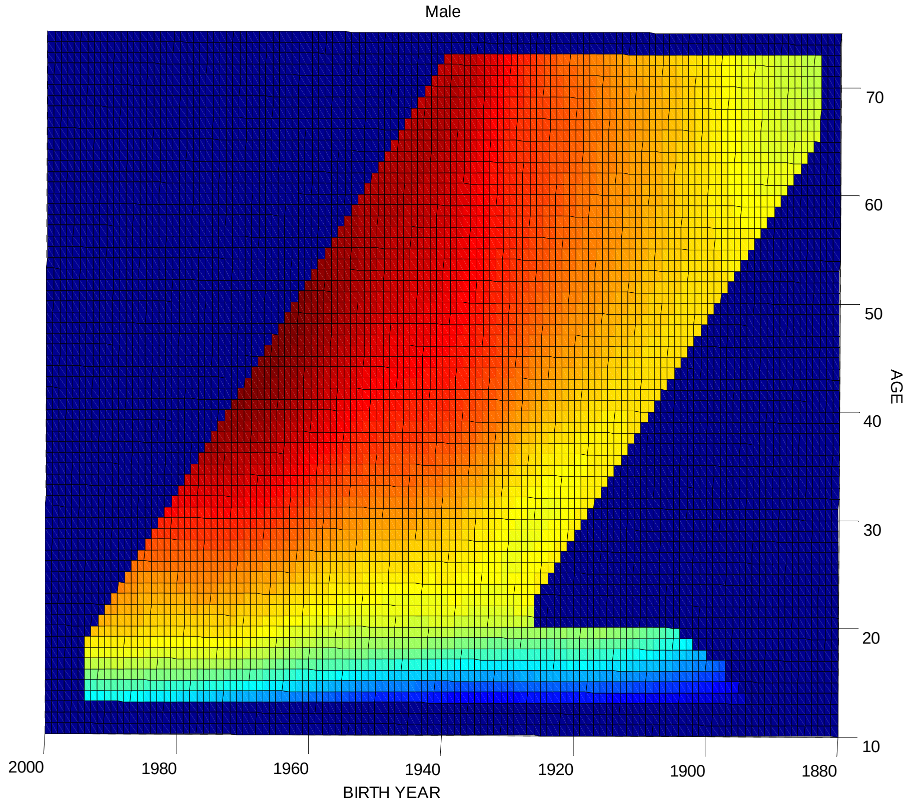


Figure 3: BMI by Age and Cohort Based on Locally Weighted Regression
Figure 3 – (a)



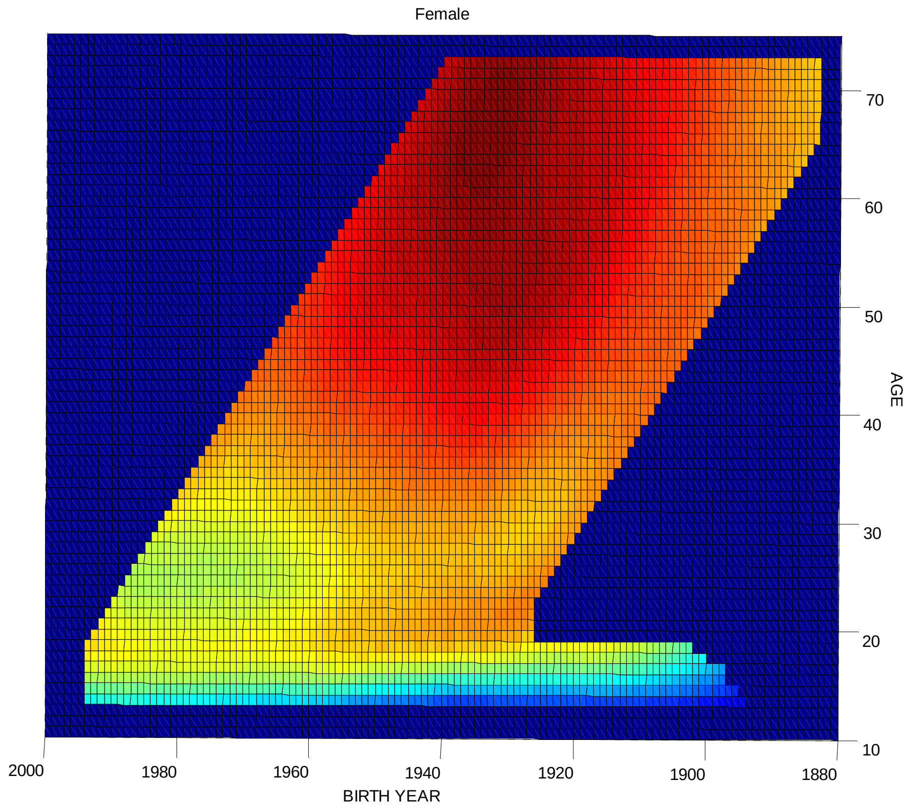
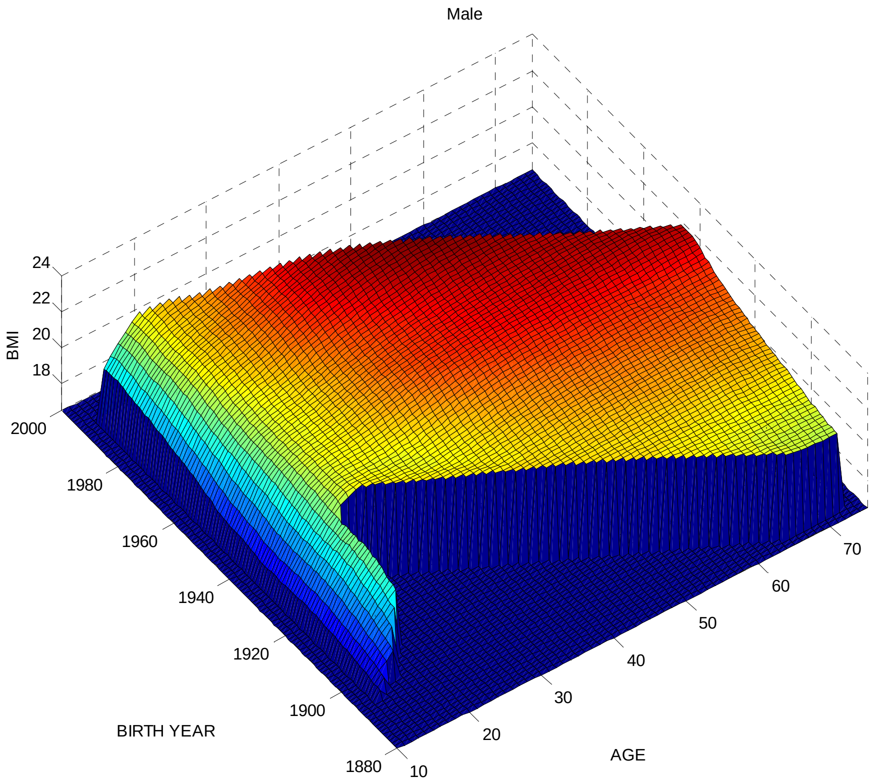


Figure 3 – (b)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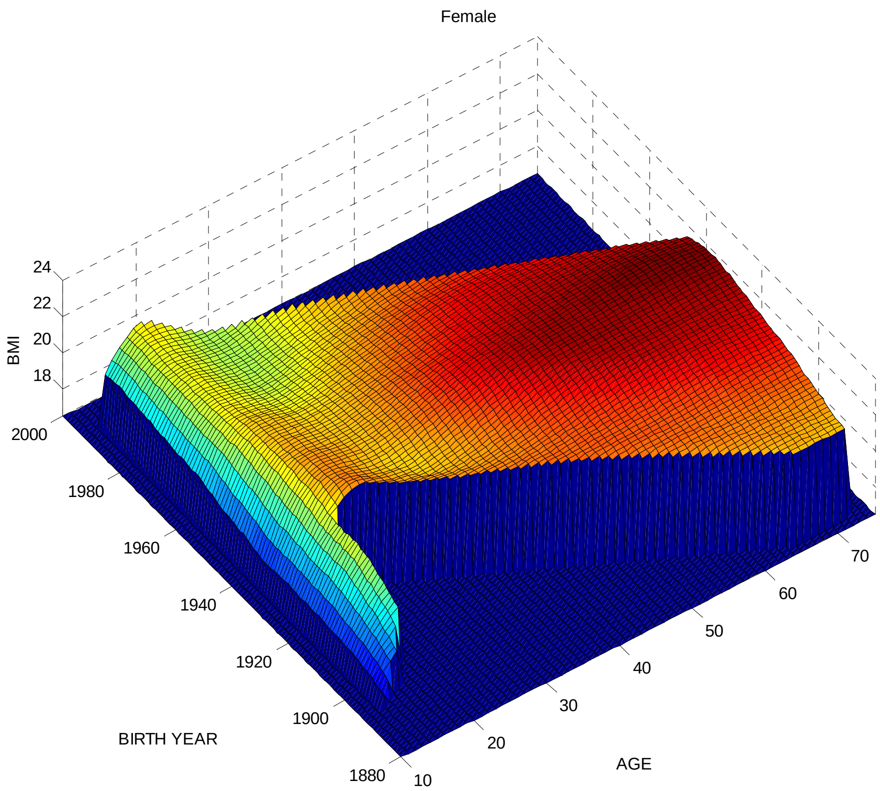
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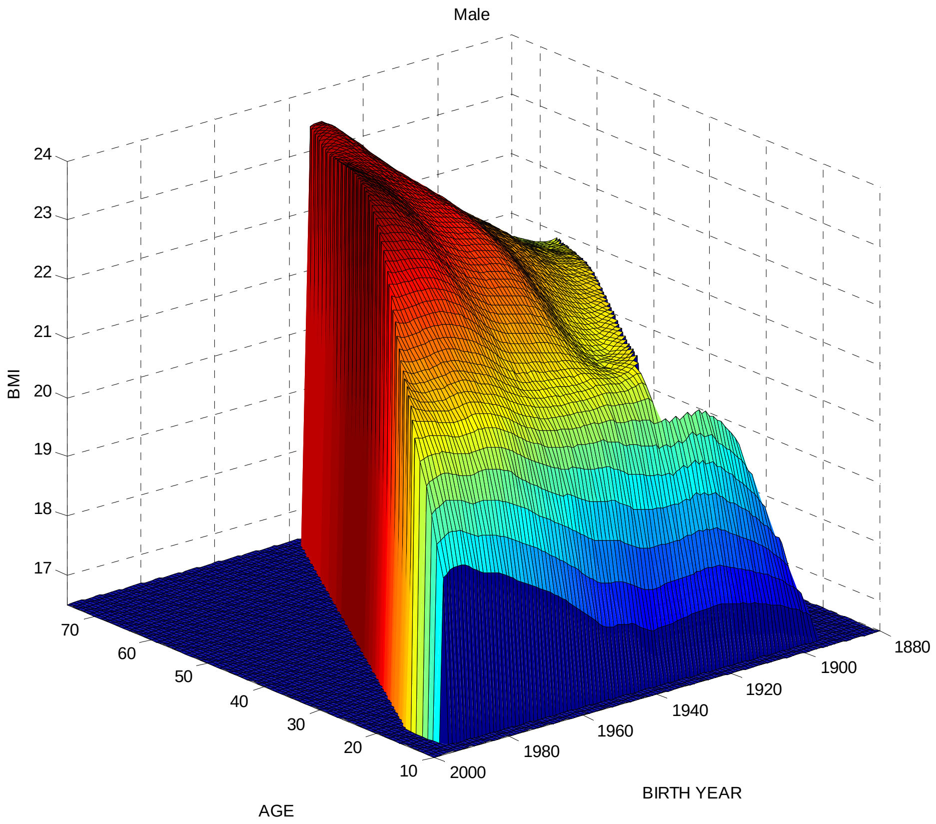
Figure 3 – (c)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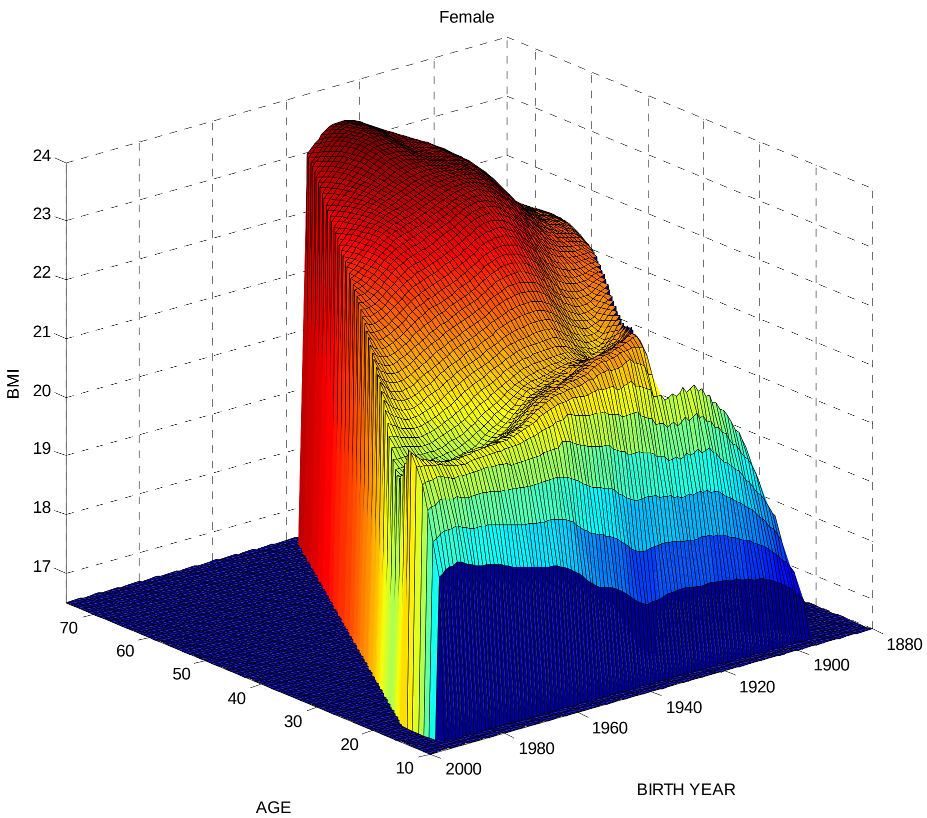
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BIRTH YEAR

Figure 4: Height by Age and Cohort Based on Locally Weighted Regression