TITLE PAGE

Obesity prevalence in the long-term future in 18 European countries and the United States based on the underlying epidemic wave pattern

Running title: Obesity prevalence up to 2100 in Europe

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Abstract (299 words)

Background/Objectives: Obesity is considered an epidemic, yet previous obesity forecasts did not take the underlying wave pattern into account, and mainly considered the short-term future and a single country (mostly the United States (US)). We will forecast obesity prevalence over the long term using the underlying epidemic wave pattern for a large number of European countries and the US.

Subjects/Methods: We modelled and projected population-level obesity prevalence data for the national populations aged 20-84, by sex of 18 non-Eastern European countries and the US. More specifically, we integrated the epidemic wave pattern into conventional mortality projections by applying the Lee-Carter forecasting technique to the transformed logit of prevalence for 1975-2016, and by linearly extrapolating the speed of change from 2000 onwards up to 2100.

Results: In 2016, age-standardised obesity prevalence was, on average, 25%. Over the 1990-2016 period, the increase in obesity prevalence slowed. Obesity is expected to reach maximum levels between 2030 and 2052 among men, and between 2026 and 2054 among women. The maximum levels will likely be reached first in the Netherlands, the US, and the UK; and last in Switzerland. The maximum levels are expected to be highest in the US (44%) and the UK (37%); and lowest in the Netherlands for men (28%) and in Denmark for women (24%). In 2060, obesity prevalence is projected to range from 13.1% (Dutch men) to 36.9% (Swiss men). As in the past, the projected age-specific obesity prevalence levels have an inverse U-shape peaking at around ages 60-69.

Conclusions: Using our novel approach, obesity is projected to reach, on average, a maximum level of 31% in 2037 in the 18 non-Eastern European countries analysed. Our projections reveal important changes in the country rankings, except for the US and the UK who are likely to maintain their forerunner positions.

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Introduction

Obesity increased dramatically over the last four decades.[1] While the United States (US) currently ranks first in obesity prevalence levels (36.5% in 2011-2014),[2] the rapid rate of obesity increase in Europe puts the continent in second place globally (average prevalence of 15.9% across EU member states in 2014).[3]

Although it took some time for obesity to be recognized as a major public health problem in Europe[4], it is increasingly seen as an important concern among European public health policy-makers.[5] As the question of how obesity will evolve in the future is viewed as especially pressing,[5] studies that could shed light on obesity's likely evolution for European countries are warranted.

Obesity is characterized by many scholars as an epidemic.[6] The use of this term has some drawbacks, as it disguises some of the characteristics of obesity, such as the endemic character of and the difficulties in defining or accomplishing an end to obesity's development. But this term appears to fit given the sharp and sudden increases in obesity, often to record-high levels.[7]

A distinct characteristic of epidemics is that they develop in a wave pattern.[8-11] In its initial stages, an epidemic increases slowly, and then more quickly. After reaching a plateau, the epidemic declines, more intensely in the beginning and more slowly toward the end. This wave pattern has, for instance, been observed in the smoking[8] and influenza epidemics.[9] Very recently, it has been proposed as a theoretical framework to describe the obesity epidemic and its likely evolution.[12]

Indeed, some existing evidence on the evolution of obesity up to now supports the notion that obesity is following the underlying wave pattern of the epidemic. Several studies have reported a stagnation or a levelling off of the obesity increase in countries like the US,[13] Russia, the former Yugoslavia, the Czech Republic, and Lithuania.[14] In addition, the stabilization of obesity trends has been observed in specific sub-populations, such as adults with high socioeconomic status in regions of Switzerland, France, and Finland.[15]

However, previous obesity forecasts did not consider obesity as an evolving epidemic. Instead, most previous obesity forecasts for one or more countries provided only short-term projections up to 2030,[16-23] with just one (to the best of our knowledge) providing projections up to 2050.[24] The methodologies employed in these previous projections differed substantially. Many previous studies on this topic applied linear forecasts that assume that obesity will increase continuously.[16,24] More recent studies took into account the recent evidence indicating that obesity prevalence may be levelling off, and projected a smaller increase up to 2030,[20] or a plateau in some countries by 2022 or 2030.[18,21] However, most of these studies included only one – usually non-European – country, mostly the US.[16,19-21,23,24] The three previous studies that included more than one European country (a maximum of five) provided forecasts that extended no more than 16 years into the future.[17,18,22] Thus, comparative long-term forecasts of obesity prevalence in Europe are clearly lacking.

This study therefore aims to forecast obesity into the long-term future using a novel approach that incorporates the underlying wave pattern of the epidemic, and will do so for 18 European countries and the US.

Data and Methods

- Setting

We forecasted how obesity will evolve in the future for the national populations, aged 20-84, in the US and 18 non-Eastern European countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the United Kingdom. We excluded Central and Eastern European countries as their past obesity trends are more irregular.[25]

- Data

Obesity prevalence data (BMI≥30kg/m2) by country, sex, age (20-24, …, 85+), and year (1975-2016) were obtained from the NCD Risk Factor Collaboration study.[25] These data comprise the available measured height and weight data, supplemented with estimates from a Bayesian hierarchical model based on information from other years and related countries. They constitute validated data that had been used previously to study long-term time trends in obesity.[26] We choose this dataset over the 2016 NCD data [27] and the data by Ng et al. 2014,[28] as it covered a longer time series.

We converted the obesity prevalence data for five-year age groups (point estimates) into single-age prevalence (20-84) by applying Loess smoothing. [29]

- Approach

We implemented the epidemic wave pattern into conventional mortality projections, by linearly extrapolating the speed of change of the logit of obesity prevalence between successive years (=velocity)(=first order difference). A wave pattern is obtained when the velocity declines linearly over time, namely, from a positive to a negative speed of improvement; while the maximum level is obtained when the speed of improvement over time becomes zero. That is, we require a constant negative acceleration (=second-order difference).

- The model

We implemented the wave shape in the benchmark mortality projection method in demography; i.e., the Lee-Carter (LC) methodology. [30,31]

The model decomposes the logarithm of age-specific mortality rates into a time-invariant age component α_x which is the average age pattern of mortality, an overall time trend κ_t which is the average rate of improvement of mortality across all ages, the magnitude of the age-specific change over time β_x and the residual error $\epsilon_{x,t}$.[31]

We applied the LC model to the logistic transformation of obesity prevalence, $\text{logit}\,\text{OP}_{x,t}$, at age x and year t, to ensure that the projected prevalence remains between 0 and 1:

$\text{logit}\,\text{OP}_{x,t} = \alpha_x + \beta_x \cdot \kappa_t + \epsilon_{x,t}$ (Equation 1)

The model fitted our data well (Table S1).

- The forecast

The obesity forecast is obtained by linearly extrapolating the velocity of obesity into the future. More specifically, we extrapolate the period parameter in our model κ_t by means of a second-order random walk with negative drift.[32] First, however, because it is not likely that future obesity prevalence will be zero,[12] we implemented lower limits for the projection of κ_t by means of the observed country- and sex-specific obesity prevalence levels in 1975, resulting in the transformed period parameter f_t.

We extrapolated the transformed period parameter f_t merely from 2000 onwards, because in this period a smaller increase in acceleration was observed than before 2000 (see Figure 1).

We forecasted age- and sex-specific obesity prevalence until 2100, and we estimated 95% projection intervals by performing 100,000 simulations. To obtain future overall obesity prevalence levels, we applied direct age standardization using the country- and sex- specific population age compositions in 2014 from the Human Mortality Database.[33]

- Sensitivity analyses

We performed different sensitivity analyses, among which the use of different data on obesity prevalence, the use of an age-period-cohort model instead of an age-period model, and the use of different calibration periods. Their outcomes are discussed in the "Evaluation of our methodology" section.

Results

In the 18 European countries in 2016, the age-standardized obesity prevalence ranged from 22.7% in Portugal to 29.3% in the UK for men, and from 19.5% in Switzerland to 31.3% in the UK for women. The age-standardized obesity prevalence was even higher in the US, at 37.5% for men and 39.5% for women.

Between 1975 and 2016, obesity increased in all the studied countries, although not uniformly (Figure 1). Especially among women, we observed a recent slowing of the increase in obesity prevalence, particularly in Finland, Greece, and Spain; and, less recently, in Switzerland (Figure 1). Our analysis of the improvement in the logit of obesity prevalence between years – i.e., the velocity – from 1990 onwards (see Figure S1) indicates that an overall decline was observed for all countries. This finding indicates that the increase in obesity prevalence is slowing down.

In Figure 2, the estimated age-standardized obesity prevalence from 1975-2016 and the projected obesity prevalence levels, with the 95% projection intervals from 2017-2100, are presented by sex for the UK and the US. Projections for all countries are presented in the Supplementary Material (Figure

S2). These figures clearly indicate that our methodology is able to forecast obesity prevalence far into the future, thereby implementing the wave pattern of the obesity epidemic.

In the UK, obesity is expected reach a maximum level of 36.9% in 2034 for men and in 2033 for women (Figure 2). In the US, obesity is expected to reach maximum levels in 2031, at 43.6% for men and 44.4% for women.

Together with Ireland (36%), the US and the UK are the countries in our study that are expected to reach the highest maximum levels (Table 1). The lowest maximum levels are for men in the Netherlands (28%) and for women in Denmark (24%). The year in which the various countries are expected to reach the maximum level ranges from 2030 in the Netherlands to 2052 in Switzerland for men; and from 2026 in the Netherlands to 2054 in Switzerland for women. Apart from the Netherlands, Norway, and Portugal, all other countries will reach their maximum levels after the US and the UK (Table 1).

According to our forecasting model, obesity will decline after these maximum levels have reached. Table 2 summarizes the projected age-standardized obesity prevalence levels, with the 95% projection intervals, for the year 2060. Among men, the prevalence levels range from 13.1% (the Netherlands) to 36.9 % (Switzerland). Among women, the prevalence levels range from 13.3% (the Netherlands) to 29.1% (the US).

Our projected age-specific obesity prevalence levels (Figure S5) display an age pattern similar to the pattern observed in the past, with an inverse U-shape peaking around ages 60-69.

Discussion

- Summary of results

In 2016, the age-standardized obesity prevalence ranged from 19.5% (Swiss women) to 39.5% (US women). Over the 1990-2016 period, the increases in obesity prevalence declined. Obesity is expected to reach maximum levels from 2030 to 2052 among men and from 2026 to 2054 among women. These levels should be reached first in the Netherlands, the US, and the UK; and last in Switzerland. The maximum levels are expected to be highest in the US (44%) and the UK (37%), and lowest in the Netherlands (28% among men) and in Denmark (24% among women). In 2060, obesity is projected to range from 13.1% (Dutch men) to 36.9% (Swiss men). As in the past, the projected age-specific obesity prevalence levels have an inverse U-shape peaking around ages 60-69.

- **Discussion of the results**

A direct comparison of our obesity prevalence projections with previous projections is hampered by the use of different forecasting methodologies, data, and age groups. Overall, however, these previous projections only provided short-term forecasts, and none of them accounted for the wave pattern of the obesity epidemic. In general, the previous forecasts that used linear extrapolation[16,24] tended to project higher obesity levels than we did; whereas the forecasts that took into account the recent observed levelling off in obesity[20,21] were closer to our findings, at least for the short term.

The wave pattern we predict follows the theoretical framework of Xu and Lam,[12] which is based on the hypothesis that the obesity epidemic will follow the wave pattern of the tobacco epidemic, as described by Lopez.[8] Xu and Lam also hypothesized more specifically that a maximum will be reached about 30 years after obesity prevalence is at 30%.[12] If we applied this hypothesis to our data, obesity would be expected to reach maximum levels between 2017 and 2044 in our studied countries (see Table S2). This timing is largely in line with our projections, although not for each and every individual country. In addition, our projection that the highest maximum level will be around 44% in the US is quite distant from the theoretical generic maximum obesity level of 60% that Xu and Lam postulated.[12] These differences in the timing and the maximum levels found can be attributed to differences in the approaches used: while Xu and Lam proposed a theoretical framework for application worldwide,[12] our approach implemented the wave pattern empirically for 18 European countries and the US. As such our paper adds a strong empirical argument, to the theoretical one, obtained from 19 countries. Moreover, by focusing on Europe and the US, our empirical application was able to capture important cross-country variations in the levels and the timing of the maximum obesity prevalence, and thus highlights the differences between countries in the timing and the impact of the obesity epidemic.

Indeed, using our novel projection methodology, the maximum obesity prevalence is expected to range from 44% (the US) and 37% (the UK) to 24% (Danish women) and 27% (the Netherlands). We project that this maximum level will be reached between 2026 (Dutch women) and 2054 (Swiss women), with the US and the UK also reaching this level early.

Our expectation that the US and the UK will hold forerunner positions in terms of both timing and levels is in line not only with a previous forecast that focused on a few European countries as well as the US,[18] but with their current forerunner positions and with the previous literature. As highlighted in the results section, the US and the UK are currently the countries with the highest obesity prevalence levels. Previous studies have also shown that the UK is the forerunner in obesity in Europe, not only because of its high obesity levels, but because its increases in obesity prevalence have been larger over time than elsewhere in Europe.[25,27,34] This increasing trend in obesity in the UK has been similar to the trend observed in the US, although the UK started from a lower level.[35] Earlier work also identified similarities in the obesity progression in the UK and the US.[36,37] The obesity levels in the UK and the US are fairly similar,[38] and the two countries share cultural characteristics that might predispose their populations to having similar eating and physical activity habits.[39,40] However, compared to the US, the UK is expected to reach lower maximum levels a couple of years later; in line with the current differences in levels and timing. It should be noted that the UK differs from the US in terms of its socioeconomic conditions, food policies, and access to food technology;[35] and that these could be the factors that explain this observed gap. All in all, however, the trends in the UK are following those in the US rather closely, while the trends in the other European countries – led by Ireland - are following.

The variations in the timing and the levels of the maximum obesity prevalence that we project for the remaining European countries can largely be explained by their current obesity prevalence rankings. The current differences between countries also reflect the timing of the obesity epidemic, and are related to differences in cultural, socioeconomic, nutritional and environmental factors.[25,41] Thus, according to our forecast, the countries with the lowest observed obesity levels in 2016 – namely, the Netherlands, Italy, and Portugal among men and Denmark and Sweden among women – are projected to reach relatively low maximum levels as well. Similarly, the countries with the highest observed current levels among both sexes, like Greece, Germany, and Ireland, are projected to reach higher levels than the other countries. These observations are in line not only with our expectations, but with a recent study forecasting obesity up to 2025 in the WHO European countries.[22]

However, our forecast does not project that all countries will keep the exactly same obesity prevalence ranking in the future that they held in the past. Among men, countries like Switzerland, Norway, and Iceland, which are ranked low or intermediate based on the latest available obesity data, are forecasted to be at intermediate or high levels in the future. Among women, countries like Iceland and Luxembourg, which are currently ranked low to intermediate, are forecasted to reach very low or intermediate levels in the future. This change in country rankings can be largely explained by the country differences in the deceleration in obesity increases observed in the data after 2000 (see Figure S1). For instance, given the observed weak deceleration in obesity increases from 2000 onwards among Swiss men, Switzerland is projected to reach its maximum obesity prevalence levels relatively late. Thus, Switzerland is expected to cross over in the rankings with countries that are expected to reach their maximum levels sooner because of a stronger deceleration. It is important for policy-makers to keep this change in country rankings in mind.

- **Evaluation of our methodology**

We decided to employ age-period modelling instead of age-period-cohort modelling, despite the importance of the cohort dimension in trends in obesity prevalence [42-44] and obesity-attributable mortality.[36] This was mainly because the application of age-period-cohort modeling to the data we used, resulted in unlikely similar cohort patterns for the different countries, because these data were estimated using a Bayesian hierarchical model that included only the age and period dimensions.[25] When forecasting obesity, the inclusion of the cohort dimension would be an important step forward, and can be easily implemented in our approach by changing the underlying model into an age-period-cohort model, and by appropriately projecting the population-specific cohort parameters.

Because of the unsteady negative acceleration patterns we observed, our choice to project the period parameter using data from 2000 onwards may have affected the outcomes of our forecast.[45] Although indeed using different calibration periods (Table S3 and S4) resulted in different levels and years in which the maximum will be reached, the same overall conclusions can be drawn.

An important element of our forecasting approach was its assumption of a constant negative acceleration and a linear decline in the speed of change over time (= velocity). Without applying this assumption, it would not be possible to obtain the epidemic wave pattern. However, the obesity data we used did not show a clear constant negative acceleration, but instead, at least from 2000 onwards a negative acceleration that is slightly increasing (see Figure S3). Still we have a strong case for its implementation because of the theory by Xu and Lam,[12] because of the observed decelerations in the increase in negative acceleration, and because, in fact, applying our model to the NCD data for 2016 and the data of Ng et al. 2014 did result in an average constant negative acceleration,[27,28] at least from 1995 onwards (see Figure S3).

Because it is not likely that future obesity prevalence will reach zero,[12] we implemented lower limits in our forecast. For this purpose, we used the country-, sex-, and age-specific prevalence levels in 1975.[25] These levels did not only represent the oldest available comparable data, but also ensured that obesity prevalence levels 85 years from now (in 2100) are higher or equal then levels 40 years ago, given that the maximum obesity prevalence will be reached in about 30 years.[12] The choice of the lower limits however affects the estimation of the acceleration, and, consequently, the level and the year the peak. For instance, very high lower limits will result in higher maximum obesity levels in later years. We feel confident about our lower limits though, because the average age-standardized level proves very close to the proposed 10% level that Xu and Lam expect obesity to reach at the final stage of the epidemic.[12] Important to note however is that through the use of lower limits the projection intervals are quite narrow and tend to get more narrow near the end.

Our projection approach assumes that the obesity epidemic will follow the general wave pattern of epidemics, based on the recent theoretical framework of Xu and Lam,[12] which assumes that obesity will reach its maximum 30 years after its prevalence is at 30% and a minimum 60 years after reaching its maximum. It should be noted, however, that the underlying epidemic wave pattern is debated by some scholars. These scholars have argued that the data have been misinterpreted due to bias, and that any stagnation is temporary, and will be followed by further increases.[15] Our observation of a deceleration in the obesity increase over the period 1990 to 2016 however provides a strong empirical argument obtained from 19 countries in line with the theoretical argument. For the observed deceleration of the obesity improvement to continue into a plateau and an eventual decline, this will – similar to any extrapolation of past trends - not be self-evident and highly depends on continued attention to the health risks of obesity, from individuals, society and public health professionals.

Conclusions and implications

Using our novel approach to project obesity prevalence into the long-term future, we expect obesity to reach maximum levels between 2017 and 2053 in the 18 non-Eastern European countries in our study sample and the US. The US and the UK are expected to achieve the highest maximum levels (at 44% and 37%, respectively) relatively soon (2031-2034), followed by the other European countries, for which the lowest estimated maximum level is 24% among Danish women.

In our approach, we implemented the underlying wave pattern of the epidemic based on the recent theoretical framework by Xu & Lam, and our observation of a deceleration in the obesity increase over the period 1990 to 2016. Thus, we project that a maximum obesity level will be reached in all countries, followed by a decline. Yet, for the current slowdown in the improvement of obesity to continue and to turn into a decline, (continued) effective public health action is required.

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Table 1. Expected maximum levels of age-standardized obesity prevalence (20-84 yrs.) and the year these levels will be reached in the 18 European countries and the US, by sex.

	Expected maximum obesity prevalence (%) and 95% projection intervals		Expected year that the maximum will be reached and 95% projection intervals	
Country	*Men*	*Women*	*Men*	*Women*
Austria	32.6 (30.4; 35.9)	25.9 (24.6; 27.9)	2040 (2035;2045)	2037 (2033; 2043)
Belgium	33.1 (31.3; 35.7)	27.1 (26.2; 28.6)	2040 (2036; 2045)	2036 (2031; 2043)
Denmark	34.2 (32.4; 36.7)	24.0 (23.1; 25.2)	2042 (2039; 2047)	2041 (2037; 2045)
Finland	34.7 (32.4; 38.6)	28.7 (27.4; 30.8)	2042 (2036; 2049)	2037 (2032; 2045)
France	31.6 (30.1; 33.9)	27.1 (26.3; 28.1)	2038 (2034; 2042)	2034 (2030; 2038)
Germany	36.4 (34.3; 39.5)	30.3 (29.1; 32.3)	2041 (2037; 2047)	2039 (2035; 2045)
Greece	37.4 (36.1; 39.0)	32.5 (32.0; 33.1)	2044 (2042; 2047)	2036 (2034; 2039)
Iceland	34.1 (32.0; 37.3)	24.1 (23.3; 25.5)	2039 (2035; 2045)	2034 (2030; 2041)
Ireland	36.7 (34.7; 39.9)	35.5 (33.9; 37.7)	2037 (2034; 2042)	2035 (2032; 2039)
Italy	28.3 (27.1; 30.1)	26.4 (25.7; 27.5)	2036 (2032; 2041)	2034 (2030; 2039)
Luxembourg	34.7 (33.3; 36.6)	26.4 (25.8; 27.3)	2037 (2035; 2041)	2033 (2031; 2037)
Netherlands	28.0 (27.1; 29.0)	25.6 (25.2; 26.0)	2030 (2028; 2032)	2026 (2024; 2028)
Norway	32.8 (30.8; 35.8)	28.8 (27.8; 30.4)	2035 (2031; 2041)	2031 (2028; 2037)
Portugal	29.4 (27.8; 31.8)	27.9 (27.1; 29.0)	2034 (2031; 2039)	2030 (2027; 2034)
Spain	35.2 (33.8; 37.0)	30.2 (29.5; 31.3)	2041 (2037; 2044)	2037 (2033; 2043)
Sweden	33.1 (31.1; 36.2)	24.6 (23.5; 26.3)	2038 (2034; 2044)	2036 (2032; 2042)
Switzerland	37.9 (35.4; 41.4)	27.1 (25.3; 29.9)	2052 (2047; 2058)	2054 (2047; 2062)
United Kingdom	36.9 (35.5; 38.8)	36.9 (35.8; 38.5)	2034 (2032; 2038)	2033 (2031; 2037)
United States	43.6 (41.7; 46.7)	44.4 (42.8; 46.9)	2031 (2028;2037)	2031 (2027; 2036)

Table 2. Projected age-standardized obesity prevalence (%) (20-84 yrs.) and corresponding projection intervals in 2060 in the 18 European countries and the US, by sex.

	Men	*Women*
Austria	25.7 (21.8; 31.6)	20.5 (18.0; 24.2)
Belgium	27.2 (24.0; 31.8)	23.2 (21.2; 26.2)
Denmark	29.3 (26.2; 33.4)	21.1 (19.4; 23.3)
Finland	29.9 (25.3; 36.4)	24.3 (21.4; 28.5)
France	24.3 (21.3; 28.4)	21.3 (19.6; 23.6)
Germany	31.0 (27.1; 36.2)	26.1 (23.7; 29.5)
Greece	33.2 (31.0; 35.9)	28.2 (27.0; 29.5)
Iceland	27.2 (23.3; 32.9)	19.5 (17.6; 22.4)
Ireland	26.5 (22.6; 32.2)	24.2 (21.2; 28.5)
Italy	21.1 (18.6; 24.6)	21.4 (19.7; 23.8)
Luxembourg	26.0 (23.3; 29.6)	19.7 (18.3; 21.7)
Netherlands	13.1 (11.8; 15.0)	13.3 (12.5; 14.4)
Norway	22.0 (18.2; 27.8)	19.8 (17.5; 23.3)
Portugal	17.9 (14.9; 22.4)	17.6 (15.8; 20.3)
Spain	30.0 (27.4; 33.3)	26.9 (25.2; 29.2)
Sweden	25.2 (21.5; 30.7)	19.7 (17.6; 22.9)
Switzerland	36.9 (33.5; 41.2)	26.8 (24.3; 29.9)
United Kingdom	24.1 (21.5; 27.7)	25.7 (23.4; 28.8)
United States	26.8 (22.6; 33.7)	29.1 (25.4; 35.0)

Figure 1. Age-standardized obesity prevalence (%) (20-84 yrs.) in 18 European countries and the US, 1975-2016, by sex.

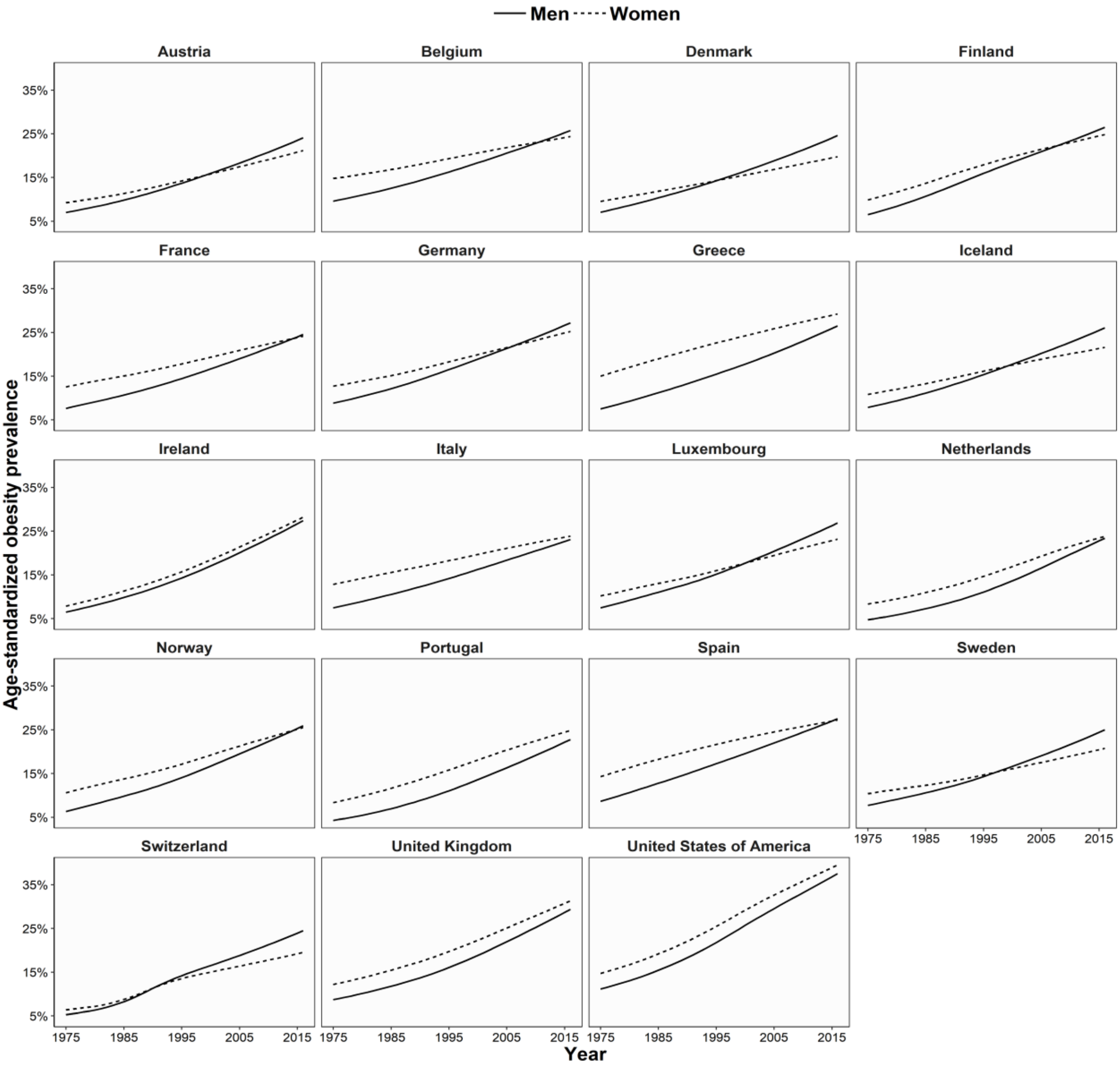
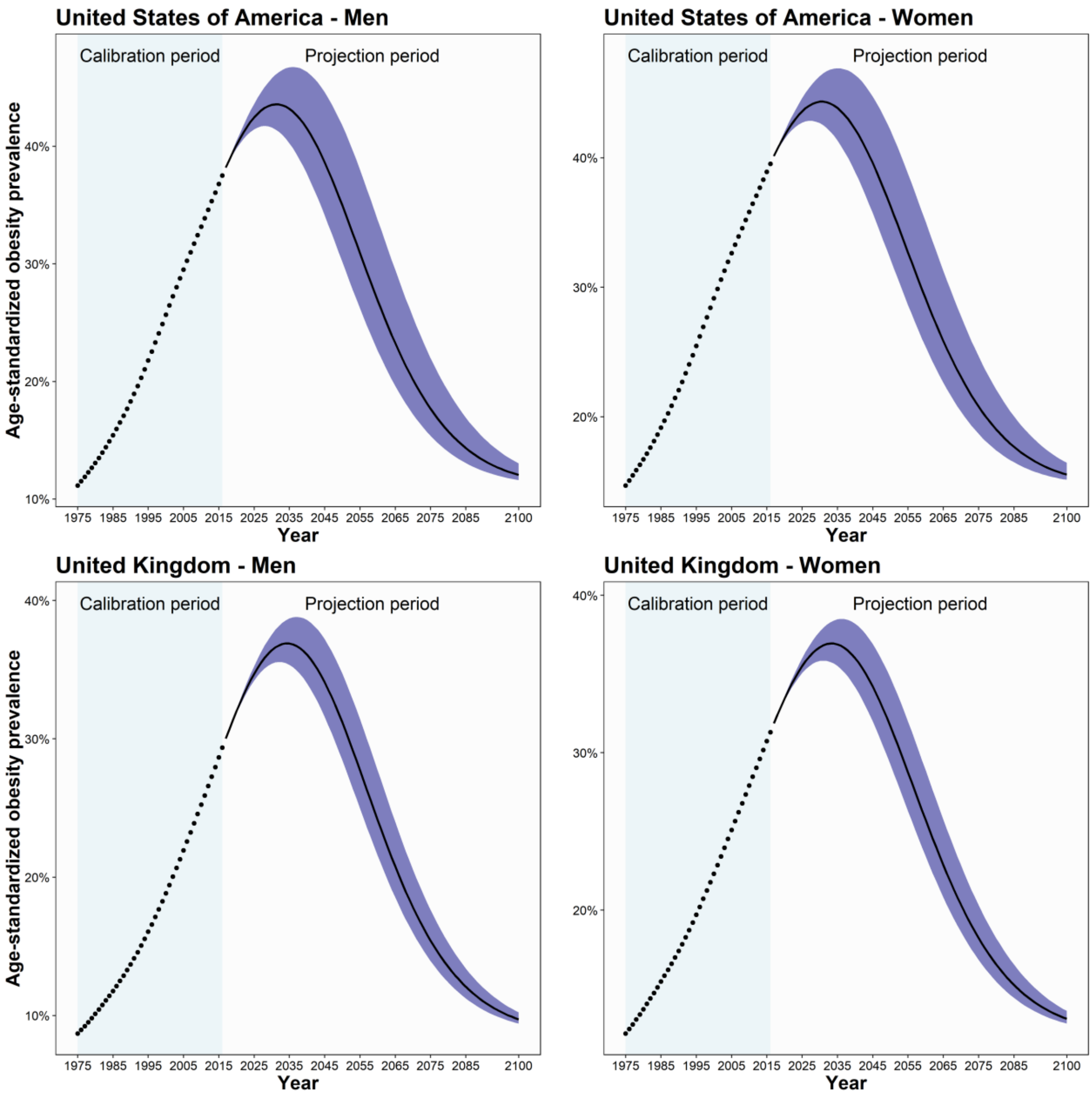


Figure 2. Estimated and projected age-standardized obesity prevalence (20-84 yrs.) and 95% projection intervals in the UK and the US, 1975-2100, by sex.



Calibration period: 1975-2016; Projection period: 2017-2100; Purple area: Projection intervals