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Abstract

We project (age-specific) alcohol-attributable mortality up to 2060 in 26 European countries by carefully assessing past trends and applying advanced projecting techniques.
We used estimated sex and age-specific alcohol-attributable mortality fractions (AAMF) among the national populations aged 20-84, for 1990 up to 2016, from the Global Burden of Disease Study, which we adjusted at older ages. We applied age-period-cohort modelling and projection, and avoided unrealistic future crossovers and differences in age-standardised AAMF between sexes and country groups, by implementing different lower bounds and by enabling that current (stagnating) increases are turned into declines.
We find that in 2016, age-standardised AAMF were substantially higher among men (10.1%) than women (3.3%), and were much higher in Eastern Europe (14.3%) than in Western Europe (8.2%) among men. From 1990 to 2016, age-standardised AAMF mostly increased in Eastern and North-western Europe, and then declined or stagnated; whereas in South-western Europe, AAMF mostly declined, albeit with decelerations, particularly among men. We project that in the future, AAMF levels will decline in all countries, and will converge across countries, but that for men, levels will be higher in Eastern and South-western Europe than in North-western Europe. For 2060, projected AAMF are, on average, 5.1% among men and 1.4% among women. In sum, the share of mortality due to alcohol is projected to eventually decline in all 26 European countries, and to converge across countries and sexes. Particularly for Eastern and North-western European countries, achieving these projected declines will require strong, ongoing public health action.

Key words: alcohol, Europe, future, mortality, alcohol-attributable mortality, time trends

What is already known on the topic

- Alcohol consumption is an important public health issue in Europe.
- Previous studies for selected European countries demonstrated the importance of the cohort dimension in describing and explaining past trends in alcohol-attributable mortality in Europe.
- The few previous projections of alcohol-attributable mortality in Europe disregarded the cohort dimension. Moreover, they provided short-term estimates only, and did not provide age-specific estimates.

What this paper adds

- Overview of past trends in age-specific and age-standardised alcohol-attributable mortality fractions in 26 European countries (1990-2016), while addressing important estimation issues.
- Novel projections of age-specific and age-standardised (20-84) alcohol-attributable mortality fractions up to 2060 in 26 European countries, by sex, while accounting for the cohort dimension and avoiding unrealistic differences and crossovers between sexes and countries.

Introduction

Alcohol consumption is an important public health challenge in Europe. Worldwide, Europe is the region with the highest levels of alcohol consumption, with 9.8 litres of pure alcohol consumed per capita per year in 2016 (WHO 2018). As excessive alcohol consumption substantially increases the risk of contracting several diseases (e.g., liver cirrhosis, alcohol use disorders, cancers, cardiovascular diseases, infectious diseases, and injuries) (Rehm et al. 2017; Wood et al. 2018), it has a large impact on overall mortality (GBD 2016 Alcohol Collaborators 2018; Rehm et al. 2019) and subsequently life expectancy (Trias-Llimós et al. 2018a) . Thus, having a clear overview of past trends in alcohol-attributable mortality, and understanding how alcohol-attributable mortality is likely to further develop in the future, is highly relevant for society, and for health policy-makers in particular.

The few previous studies on alcohol-attributable mortality that employed both a comparative and a temporal approach revealed important country differences within Europe (Kraus et al. 2015a; Trias-Llimós et al. 2017, 2018a; GBD 2016 Alcohol Collaborators 2018; Rehm et al. 2019; WHO 2019; Shield et al. 2020). In general, Eastern European countries experience high levels of alcohol attributable mortality - particularly among men - with strong increases (mainly in the 1990s), followed by recent declines. Southern European countries, however, generally experienced declining trends over the last 30-40 years, resulting in lower levels. In Western and Northern European countries trends in alcohol-attributable mortality over the last decades are less clear and tend to be stagnating with periods of modest increase as well as periods with modest decrease. Studies for selected European countries demonstrated the importance of the birth cohort dimension in describing and explaining past trends in (age-specific) alcohol-attributable mortality (Kraus et al. 2015a; Trias-Llimós et al. 2017), in line with the previously observed cohort effects in alcohol use (Meng et al. 2014; Kraus et al. 2015b). These findings suggest that individuals born in the same year tend to adopt similar drinking behaviours during young adulthood, which affects their subsequent drinking patterns and alcohol-related health problems (Kraus et al. 2015a; Trias-Llimós et al. 2017).

The few previous studies that forecasted alcohol-attributable mortality employed methodologies that mainly provided all-age estimates for the short-term future. Sheron et al. (2011, 2012) projected all-age alcohol-attributable liver death rates and numbers in the United Kingdom up to 2030/2036 by linearly extrapolating the observed increase over the last 8-10 years, and by applying as alternative scenarios the past declining trends from either France, Italy, or the European Union. Pruckner et al. (2019) linearly projected declines between 1979 and 2015 in age-standardised death rates for selected alcohol-related causes of death up until 2030 for 29 European countries. Similarly, Rosén and Haglund (2019) obtained for Sweden an estimate of overall alcohol-related mortality for the short-term future only (for 2025), while considering the cohort dimension. They applied age-period-cohort modelling to mortality from four main alcohol-related causes from 1969 through 2015. Their assumption of unchanged effects of cohort and age is, however, questionable. Trias-Llimós et al. (2020) employed a more advanced age-period-cohort methodology to project age-specific mortality from four main alcohol-related causes plus liver cirrhosis in France up to 2050, and demonstrated the relevance of cohort effects in all-age and age-specific projections.

These previous studies estimated and projected alcohol-attributable mortality based on causes of death, while either including all deaths from causes that are only partly related to alcohol (e.g., external causes of death)(Pruckner et al. 2019), or excluding these deaths (Rosén and Haglund 2019; Trias-Llimós et al. 2020). However, neither approach fully reflects the whole impact of alcohol on mortality (Trias-Llimós et al. 2018b).

Our objective is twofold: first, to provide an overview of past trends in alcohol-attributable mortality in 26 European countries (1990-2016) using estimates that better reflect alcohol-attributable mortality; and, second, to obtain for the first time estimates of age-specific and age-standardised alcohol-attributable mortality for the long-term future in 26 European countries, while accounting for the cohort dimension and avoiding unrealistic future differences and crossovers between sexes and countries.

Data and methods

- Setting

We studied past trends in age-specific and age-standardised alcohol-attributable mortality fractions, and projected these trends into the future for the national populations aged 20-84, by sex, in 26 European countries. We studied past trends over the period 1990 up to 2016, or the latest available year (LAY). Consequently, we could study the cohorts born between 1906 (year 1990 minus age 84) and 1996 (year 2016 minus age 20). See Appendix Table I for the included countries, calendar years, and birth cohorts.

The alcohol-attributable mortality fraction (AAMF) represents the share of all-cause mortality in the population that is attributable to alcohol, or in other words the proportion of mortality that would not have occurred if the whole population had been a lifetime abstainer (Kehoe et al. 2012).

- Data

We used estimated alcohol-attributable mortality rates by sex and five-year age groups from the Global Burden of Disease (GBD) study 2017 (Stanaway et al. 2018; IHME 2019). These estimates include both the deaths from causes of death wholly related to alcohol, and an estimate of the alcohol-related deaths from causes of death partly related to alcohol based on alcohol consumption data and relative risks of dying at different levels of drinking. Because the GBD estimates of alcohol-attributable mortality for the highest ages (65+) are considered implausible (Trias-Llimós et al. 2018b; Manthey and Rehm 2019) we adjusted these estimates using the more realistic age pattern for the highest ages – but not the level – of causes of death wholly attributable to alcohol, using data from the WHO Mortality Database (WHO

2018) and the Human Cause of Death Database (2017). For more details, see the supplementary information (pages 23 – 40).

To obtain age-and sex-specific AAMFs we divided the alcohol-attributable mortality rates by all-cause mortality rates from the Human Mortality Database (HMD)(2018), and subsequently applied Loess smoothing to obtain the AAMF by single year of age ($AAMF_{x,t}$) instead of by five-year age groups.

To allow for comparison over time, we estimated age-standardised AAMFs using the country- and sex-specific age distribution of deaths in 2010 from the HMD (2018).

- **Projection approach**

We employed a projection approach that can result in realistic estimates of age-specific and age-standardised alcohol-attributable mortality for the long-term future. That is, by employing age-period-cohort modelling, we take into account the importance of the cohort dimension, next to the age and period dimensions, in past trends in alcohol-attributable mortality. In addition, we avoid unrealistic future crossovers and divergence in age-standardised AAMF between country groups and sexes, which can easily occur when extrapolating into the long-term future the largely different past trends for the different populations. More specifically, by implementing assumed country group- and sex-specific lower limits of future age-standardised AAMF we ensured that projected AAMF levels for men remain higher compared to those projected for women, whom historically always exhibited (much) lower AAMF levels. Similarly, based on past observations, we considered it unlikely that among men, the (much) higher current age-standardised AAMF values in Eastern European countries would become lower in the future than those in Western European countries. Moreover, we avoided unrealistic future divergence between countries in age-standardised AAMF levels by assuming that the current increases in AAMF observed for selected countries will eventually turn into declines. This assumption was motivated by the observation of such a wave-shaped pattern of increase followed by decline for AAMF in a number of European countries (see Figure 1), by the occurrence of large recent reductions in alcohol consumption particularly in Eastern Europe (Probst et al. 2020), by declining alcohol use among the youth (Kraus et al. 2015a), by the recent implementation of strong alcohol prevention policies in European countries (Probst et al. 2020), and evidence that prevention policies have the power to bend increases into declines (Probst et al. 2020).

- **Methods** (for more details, see the supplementary information (pages 23 – 40))

We projected the $AAMF_{x,t}$ for the sex-specific populations aged 20-84 up to 2060 by employing an advanced age-period-cohort projection methodology. We utilized the age-period-cohort modelling approach by Clayton and Schifflers (1987), which decomposes mortality in the shared linear trend between period and cohort (drift), a non-linear period effect, and a non-linear cohort effect. To simplify the interpretation and the projection, we clubbed the drift with the non-linear period effect using the Cairns et al. (2009) approach.

In applying the APC model to the $AAMF_{x,t}$, we used a generalised logit as the link function. The logit transformation ensured projected AAMFs between zero and one, and enabled us to project (eventually) declining AAMF for selected countries with currently increasing AAMF. The generalisation enabled the implementation of the more restricted lower limits.

The model we applied is:

$$logit\left(\frac{AAMF_{x,t} - LB_x}{UB_x - LB_x}\right) = \tilde{\alpha}_x + \tilde{\kappa}_t + \tilde{\gamma}_{t-x}$$

where LB_x represents the time-constant but population-dependent age-specific lower bounds; UB_x represents the age-specific upper bounds, which equal one; and α_x, κ_t, and γ_{t-x} capture the age pattern, the overall time trend, and the cohort deviations from the overall trend, respectively.

To obtain the age-specific lower bounds, we assumed different lower limits of age-standardised AAMF for different population groups (see Table S1), and applied to these lower limits the population-specific age pattern observed in 2016/LAY. The different lower limits for the different population groups were based on their past trends and their past (peak) levels of age-standardised AAMF. In line with past observations, the implemented lower limits were generally higher for Eastern European than Western European countries; and for Western European countries, they were generally between 1.5 to three times higher for men than for women.

For the projection of the period (κ_t) and cohort (γ_{t-x}) parameters - which we derived from the application of the abovementioned model - , we employed different strategies according to their past trends. See Box S1. The period parameter was projected by a quadratic curve with correlated errors for populations with predominantly increasing κ_t trends; and, for populations with predominantly declining trends, by extrapolation of the (recent) decline by the best-fitting Auto Regressive Integrated Moving Average (ARIMA) model with drift, subject to some restrictions. When the decline in k_t was followed by a recent increase, we projected a stable κ_t trend. After burning the outer three, five, or seven cohorts dependent on a statistical significance test, the recent trends for the cohort parameters were also projected by the best-fitting ARIMA model, subject to some restrictions. In the few cases in which this would lead to an increase, we projected a stable trend.

By performing 50,000 simulations, we obtained projected age-specific and age-standardised AAMF up to 2060, and their 95% projection intervals, by country and sex.

Results

In Europe in 2016/LAY, the age-standardised alcohol-attributable mortality fractions (AAMF) (20-84) were highest among Eastern European men (14%), and lowest among men in Norway and Iceland (5%) (Table 1). The age-standardised AAMF were substantially lower among European women (3.3%) than European men (10.1%). Among women, the age-standardised AAMF ranged from 1% in Greece to over 5% in Luxembourg, and differences in AAMF levels between Eastern and Western Europe are small.

There were substantial differences between European countries in the trends over time (1990-2016) in AAMF (Figure 1). In the South-western European countries of Austria, France, Germany, Switzerland, Greece, Italy, Portugal, and Spain, AAMF diminished over the 1990-2016 period, albeit with considerable decelerations in the decline, and even periods of stagnation, particularly among men. For men and women in the remaining countries (particularly Eastern and North-western European countries), we observed either an increase followed by a decline (Denmark, Finland, Sweden, Ireland, Czech Republic, Hungary, Russia), an increase followed by stagnation (Belgium, Luxembourg (men), Norway, United Kingdom, Ukraine, Lithuania), or an ongoing increase (Iceland, Luxembourg (women), the Netherlands, Belarus, Poland).

The trends in the period parameter (k_t) (Table S2) largely resembled the trends in age-standardised AAMF, although differences also existed, indicating an important additional effect of the cohort dimension. For example, for Austrian and German men, the trends in k_t were more favourable than the trends in age-standardised AAMF; whereas for Lithuanian and Swedish men, and for Belgian, Finnish, and Ukrainian men and women, the recent stagnation of the increase in age-standardised AAMF was less clear or absent for k_t. The cohort parameter (g_c) most often evolved as an inverted U-shaped curve (Table S3). In South-western European countries, the recent cohort trends were mainly unfavourable.

We projected long-term declines in age-standardised AAMF in all 26 European countries (Figure 2). For men in Iceland, the Netherlands, and Poland, an initial increase is projected. The projected declines are stronger among men than women, which leads to convergence, except in Germany, Greece, and Italy. However, there are no crossovers.

The projected declines are smaller for countries with past decelerating declines (mostly South-Western European countries) than for the Eastern European countries and the remaining non-Eastern (mostly North-western) European countries, which only recently experienced more rapid declines, or stagnating/ongoing increases (Figure 3). AAMF levels are projected to converge across countries. However, particularly for men, the projected AAMF levels in 2060 are higher in Eastern Europe and in South-Western European countries with (decelerating) declines than in the remaining, mostly North-western European countries.

Averaged across the 26 European countries, the projected age-standardised AAMFs in 2060 are, on average, 5.1% among men, and 1.4% among women (Table 1). Among men in Western Europe, AAMF are projected to decline from, on average, 8.3% in 2016/LAY to 6.4 % in 2030, 5.1 % in 2045, and 4.5% in 2060. For men in Eastern Europe, AAMF are projected to decline, on average, from 14.6% in 2016/LAY to 9.5% in 2030, 7.1% in 2045, and 6.0% in 2060. Among men, the highest AAMF levels are projected for Belarus up to 2046, and for Portugal thereafter; and the lowest AAMF levels are projected in Norway up to 2053, and in Iceland thereafter. Among women, the projected AAMF levels and their decline are, on average, rather similar for Eastern and Western Europe. Iceland is expected to have the lowest AAMF levels from 2030 onwards, whereas France (up to 2057) and the Netherlands (from 2058 onwards) are expected to have the highest AAMF levels.

The projections of age-specific AAMF (Appendix Figure 1; Detailed projections by country and sex (page 41 and onwards)) indicate that in the majority of populations, age-specific levels will be converging. For men in Austria, Germany, Greece, Italy, the Netherlands, Slovenia, Spain, and Switzerland, for whom only moderate declines are projected, this convergence is less clearly visible. The age pattern of AAMF, which was characterised in 2016 by an inverted U-shaped curve peaking around age 50, and with high levels at younger ages as well in Western Europe, is projected to stay approximately the same in the majority of countries (Appendix Figure 2), albeit with some shifts in the peak age, which are particularly pronounced for populations with stagnating period declines combined with recent cohort increases (e.g., Germany (men), Greece (women), Italy, Spain, Portugal (men)).

Discussion

- Principal findings

In 2016, the age-standardised AAMF were substantially higher among men (10.1%) than women (3.3%); and were much higher in Eastern Europe (14.3%) than in Western Europe (8.2%) among men. From 1990 to 2016, age-standardised AAMF mainly increased in Eastern and North-western Europe, and then declined or stagnated; whereas in South-western Europe, AAMF mostly declined, albeit with decelerations, particularly among men. We project that in the future, AAMF levels will decline in all countries and will converge across countries, but that for men, levels will be higher in Eastern and South-western Europe than in North-western Europe. The projected AAMF for 2060 are, on average, 5.1% among men and 1.4% among women.

- Evaluation of data and methods

We carefully assessed past trends in alcohol-attributable mortality using an estimation that deals with important shortcomings of previous estimates. Compared to previous research that mostly adopted an underlying cause-of-death approach (Trias-Llimós et al. 2018b), our estimates – which are largely based on those by the GBD – include mortality due to alcohol from causes of death partly attributable to alcohol. Thus, our estimates are higher than the estimates by Rosén and Haglund (2019) and by Trias-Llimós et al. (2020), which were only based on causes of death wholly related to alcohol, and are lower than estimates that include all deaths from causes of death partly attributable to alcohol (e.g., external causes of death), like the estimates by Pruckner et al. (2019). Input for our estimate of alcohol-attributable mortality *fractions*, were the GBD alcohol-attributable mortality *rates*, which we adapted at higher ages in response to quality concerns due to limitations of applying the estimation technique at higher ages (Trias-Llimós et al. 2018b; Manthey and Rehm 2019). Compared to the very steep increases (men) and steep declines (women) in alcohol-attributable mortality rates with age observed in the GBD data, we obtained an inverted U-shaped curve for both sexes (Appendix Figure S1), which is more realistic (Trias-Llimós et al. 2018b). Consequently, compared to the GBD, our estimates tend to be lower for men and higher for women (Appendix Figure S2), and are more likely to accurately represent the age pattern of alcohol-attributable mortality, and, in turn, its cohort patterns.

The use of a certain estimation technique affects not just past alcohol-attributable mortality levels (Trias-Llimós et al. 2018b), but can also affect its past trends and consequently its future trends and levels. For example, the past declines in alcohol-attributable mortality throughout Europe that Pruckner et al. (2019) reported are inconsistent with our current findings as well as with previous findings (Kraus et al. 2015a, Trias-Llimós et al. 2017; Shield et al. 2020) that showed different trends for different countries. This is likely because Pruckner et al. included mortality from all external causes, which are not all attributable to alcohol, and which declined throughout Europe (GBD 2016 Causes of Death Collaborators 2017; WHO 2019).

Despite our efforts to improve current alcohol-attributable mortality estimates, our estimates remain estimates based on the current epidemiological evidence on the effects of alcohol on causes of death and age groups; and should be considered as such.

Our advanced approach to project alcohol-attributable mortality is - in our view - an important step forward compared to the current methodologies that mainly provided all-age estimates for the short-term future (Sheron et al. 2011, 2012; Pruckner et al. 2019; Rosén and Haglund 2019). That is, our age-period-cohort approach enabled us to take into account important trend breaks - due to changes in alcohol-consumption and cohort effects in alcohol-attributable mortality - and to obtain realistic future estimates of age-specific alcohol-attributable mortality. Moreover, in contrast to the previous projections by Sheron et al. (2011, 2012) and Pruckner et al. (2019), which basically used linear extrapolation of past trends, our projection approach is able to produce plausible long-term outcomes. That is, by transforming the outcome measure, implementing lower bounds, and assuming that increases will eventually turn into declines, we avoided not only long-term estimates below zero, but also unlikely crossovers and divergence in AAMF levels both between sexes and between country groups. Both such outcomes can easily occur when linearly extrapolating past trends for different countries with largely different past trends.

Our outcomes, however, depend - like any projection - on the underlying assumptions.

Firstly, our assumption that increases in AAMF are followed by declines, to avoid unrealistic divergence in AAMF between countries, could be considered overly optimistic. Indeed, this assumption requires strong (continued) policy efforts and increased awareness of the harmful effects of alcohol. However, our observations of (i) more favourable cohort patterns for countries with recent period increases, and (ii) of recent declining or stagnating AAMFs for selected ages in most of these countries (e.g., United Kingdom, Lithuania, the Netherlands, Poland) (Table S3; Detailed projections by country and sex (page 41 and onwards)), are in line with our general assumption, which is also backed up by trends in other European countries, and by recent alcohol consumption patterns (see projection approach).

Secondly, our outcomes in the long run are – logically - dependent on the lower bounds we implemented. In fact, the implementation of these lower bounds, to avoid crossovers between the historically (much) higher alcohol-attributable mortality levels for men compared to women, and similarly – among men - for Eastern Europe compared to Western Europe, could be considered conservative particularly for those countries with currently high and strongly declining alcohol-attributable mortality. Overall, however are projections of (eventual) declines with a lower bound seem to reflect the further (decelerating) decline in alcohol consumption for Europe as a whole that was recently projected by Manthey et al. (2019).

Also, our outcomes come with uncertainty, that our projection intervals – unfortunately – do not fully capture. Firstly, our implementation of the lower bounds resulted in relatively small projection intervals, which furthermore – rather unconventionally - decrease with time. Secondly, more in general, projection intervals hardly ever fully reflect the full uncertainty of projection outcomes, which can emerge not only from model uncertainty, but also from parameter uncertainty and uncertainty related to the underlying assumptions and explicit choices (Stoeldraijer et al. 2013). In fact, we consider our projections for men in Eastern European countries – particularly in Ukraine and Lithuania – more uncertain than those for other populations. Particularly, the combination of the assumed lower bound value with the quadratic curve extrapolation resulted in projected declines for men in Ukraine and Lithuania that were particularly large and even resulting in temporal crossovers with Western European countries.

Thus, although we devised a general methodology to realistically project alcohol-attributable mortality into the long-term future, our outcomes are dependent on our assumptions, and for selected countries further methodological advancements or refinements in assumptions based on additional national knowledge would be beneficial.

Also, we acknowledge that we could not include in our analysis the foreseen, but currently unknown exact effects of the COVID-19 pandemic. In fact, both declines due to decreases in people's ability to afford alcohol as a result of an economic downturn and increases due to increases in hazardous drinking because of increased unemployment and perceived stress, can be expected (Rehm et al. 2020).

- **Interpretation of findings**

The important country differences we observed in past age-standardised AAMF levels and trends, particularly among men, can be directly related to differences in alcohol consumption levels and trends

(WHO 2019, 2020), which may, in turn, be traced back to differences and changes in socio-economic conditions, drinking cultures across Europe, and preventive actions (Allamani et al. 2014). The high AAMF levels found among adult Eastern European men can, for example, be linked to their risky drinking patterns involving the high consumption of spirits (Leon et al. 2009), which were aggravated in periods of economic hardship (Shkolnikov et al. 1998). The recent declines in alcohol consumption in Eastern Europe have been attributed to the implementation of preventive health policies, and to a moderate shift away from drinking spirits and towards consuming beer in a context of economic stabilisation (Grigoriev and Andreev 2015; Nemtsov et al. 2019; Probst et al. 2020). For North-western European countries, the observed (past) increases in AAMF reflect (temporarily) increasing (Finland, Iceland, Ireland, Norway, Sweden, United Kingdom) or stagnating alcohol consumption patterns (Belgium, Denmark, Netherlands) (WHO 2019, 2020), which have been attributed to the increasing availability and affordability of alcohol (Anderson and Baumberg 2006), combined with an expanding culture of heavy episodic drinking that is especially dangerous to health (Mladovsky et al. 2009). The declines in Southern European countries can be linked to the move away from the heavy consumption of wine, particularly during meals, and towards the consumption of beer, in line with wider societal changes (Allamani et al. 2014). Country differences within regions may be explained by differences in the implementation of (successful) preventive policies (WHO 2019; Probst et al. 2020).

We projected that AAMF levels will converge across countries, but also that for men, AAMF levels will be higher in Eastern and South-western European countries than in North-western European countries. The high future levels for Eastern European men are mainly attributable to their high past levels. However, the high future levels for South-western European men can be related to the deceleration in the decline in their alcohol-attributable mortality (Figure 1), but also to their more unfavourable recent cohort patterns (Table S3). These observations could indicate that the potential for future consumption declines in South-western European men is hampered not only by the same factors that were causing increases in North-western European countries (e.g., increases in heavy episodic drinking could have resulted in more unfavourable recent cohort trends), but also by the persistence of high levels of wine consumption in these countries (WHO 2018).

In addition, we projected declines in all countries, even for selected Eastern and North-western European populations for whom (stagnating) increasing trends have recently been observed. As mentioned already ("Evaluation of data and methods"), for the projected declines to occur in these countries, strong, ongoing efforts aimed at reducing excessive alcohol consumption and its negative health effects are needed. Also, for the remainder of countries, our projections rely on the assumption that the recent favourable trends will continue. Given that these recent favourable trends are at least partly driven by effective public health efforts, continued public health action is required for these countries as well.

- **Overall conclusion**

Our careful assessment of alcohol-attributable mortality levels and trends over time revealed important differences between European countries and men and women. Applying our advanced projection methodology to the past trends in 26 European countries - without including the as yet unknown effects of the COVID-19 epidemic -, we project that the share of mortality due to alcohol will decline in all countries, and will converge across countries and sexes. To ensure that these declines occur as projected, strong, ongoing public health action is required, particularly for selected Eastern and North-western European countries.

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Table 1 - Current and future age-standardised alcohol-attributable mortality fractions (%, ages 20-84), for selected years in 26 European countries, by country, country group (unweighted averages), and sex.

	Men				Women			
Country/Region	LAY*	2030	2045	2060	LAY	2030	2045	2060
Non-Eastern Europe - (decelerating) decline								
Austria	10.79	10.40	9.53	9.13	3.43	3.28	2.89	2.48
France	11.14	10.27	9.20	8.05	4.23	3.55	3.01	2.53
Germany	9.27	9.08	8.83	8.94	3.40	2.98	2.64	2.41
Greece	5.89	6.08	6.14	6.22	1.17	1.21	1.29	1.28
Italy	5.75	5.50	5.74	5.65	1.93	1.54	1.35	1.21
Portugal	12.53	11.99	11.42	10.84	2.92	2.44	2.07	1.79
Spain	9.84	9.34	9.07	8.24	3.14	2.73	2.43	2.09
Switzerland	6.06	5.68	5.22	4.91	3.50	3.09	2.78	2.48
Other non-Eastern Europe								
Belgium	8.65	4.13	2.10	2.00	3.93	2.27	0.93	0.68
Denmark	10.33	6.45	2.87	2.08	4.72	2.96	1.63	1.29
Finland	11.68	8.99	4.72	2.68	3.69	1.22	0.68	0.66
Iceland	4.93	4.02	1.81	0.58	1.81	0.43	0.09	0.08
Ireland	8.71	3.35	2.05	2.00	3.65	1.15	0.68	0.66
Luxembourg	10.95	4.34	2.11	2.00	6.34	3.04	1.46	1.26
Netherlands	6.07	6.80	6.11	4.84	3.18	2.93	2.79	2.58
Norway	4.68	1.97	1.06	1.00	2.49	1.41	0.56	0.35
Sweden	5.34	3.06	1.32	1.02	3.03	2.12	1.21	0.80
United Kingdom	5.35	3.48	1.54	1.06	2.58	1.53	0.60	0.36
Central Europe								
Czech Republic	11.02	7.96	5.45	5.03	2.88	1.85	0.90	0.68
Hungary	14.78	11.54	9.29	7.83	3.08	2.41	2.16	2.07
Poland	12.83	11.59	6.71	5.17	2.72	0.84	0.35	0.33
Slovenia	7.61	6.84	6.07	5.52	2.33	1.77	1.38	1.15
Former Soviet Republics								
Belarus	18.07	15.77	11.69	8.81	4.29	3.21	2.25	2.02
Lithuania	16.81	6.14	5.01	5.00	3.37	0.70	0.50	0.50
Russia	17.43	8.24	7.51	7.50	4.31	2.31	2.00	2.00
Ukraine	15.45	8.04	7.50	7.50	4.31	2.01	2.00	2.00
Unweighted averages								
non-Eastern European countries	8.22	6.39	5.05	4.51	3.29	2.22	1.62	1.39
Eastern European countries	14.25	9.51	7.40	6.54	3.41	1.89	1.44	1.34
European countries	10.08	7.35	5.77	5.14	3.32	2.11	1.56	1.37

*LAY = latest available year, which ranges from 2013 up to 2016. See Appendix Table 1 for the data availability by country.

Figure 1 - Past trends age-standardised alcohol-attributable mortality fractions (20-84), 1990-2016*, by country and sex *or latest available year

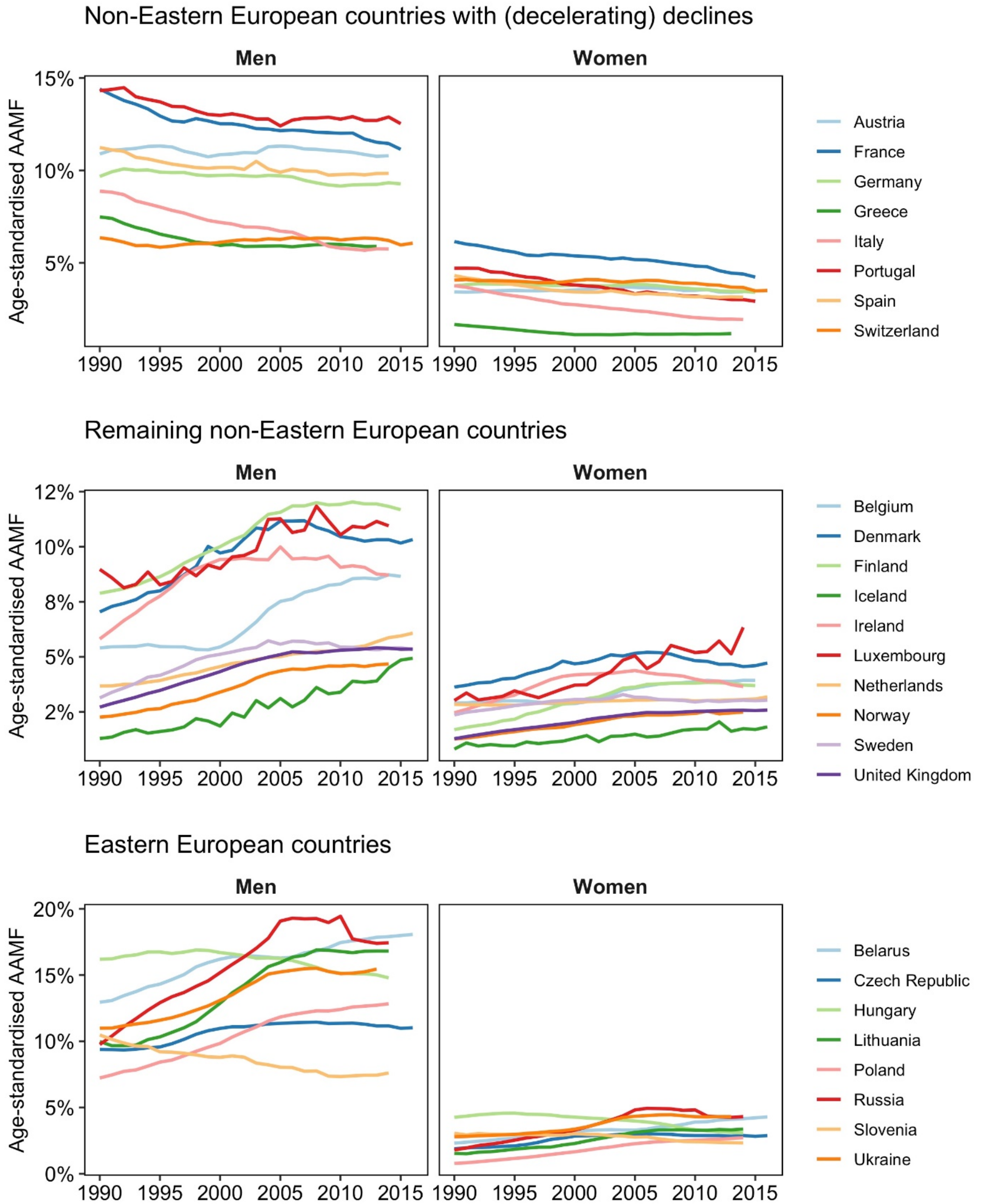


Figure 2 – Past and future trends age-standardised alcohol-attributable mortality fractions (20-84), 1990-2060, by country and sex

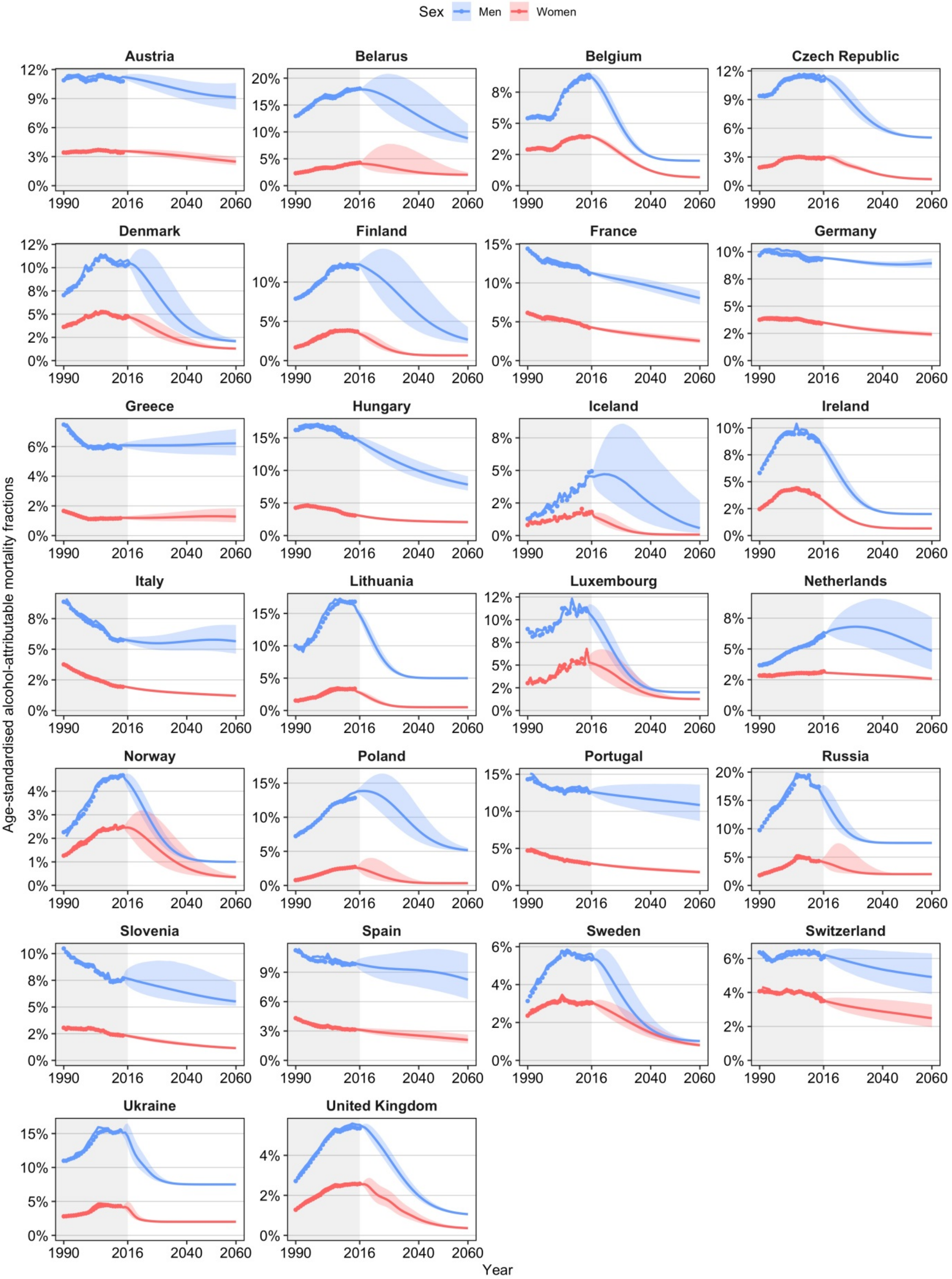
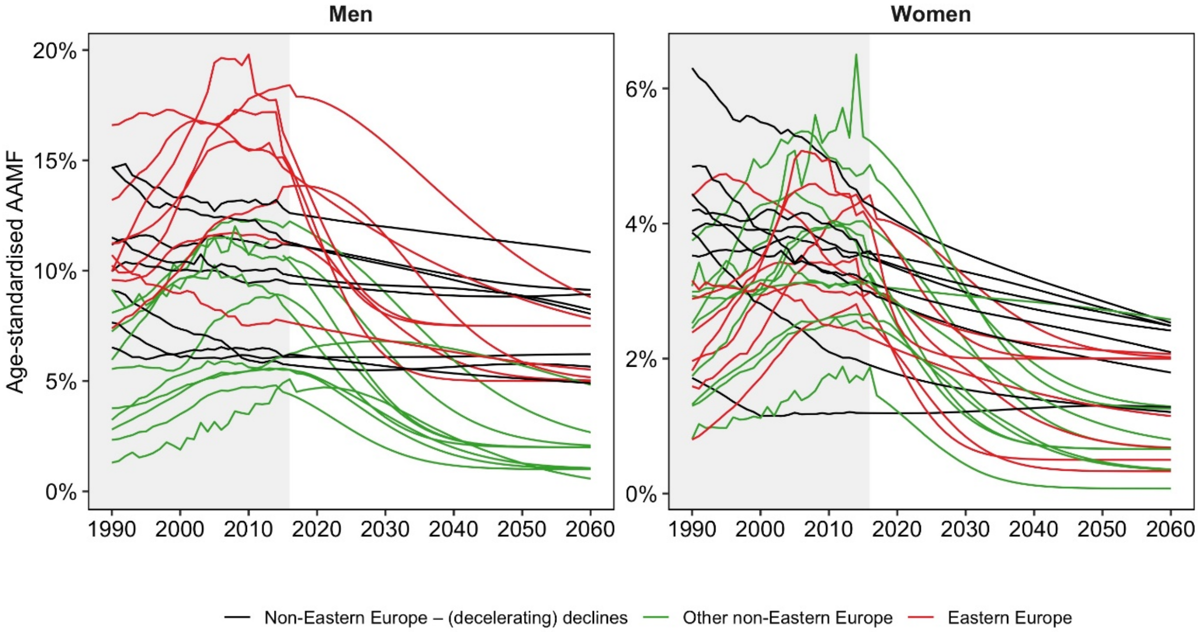
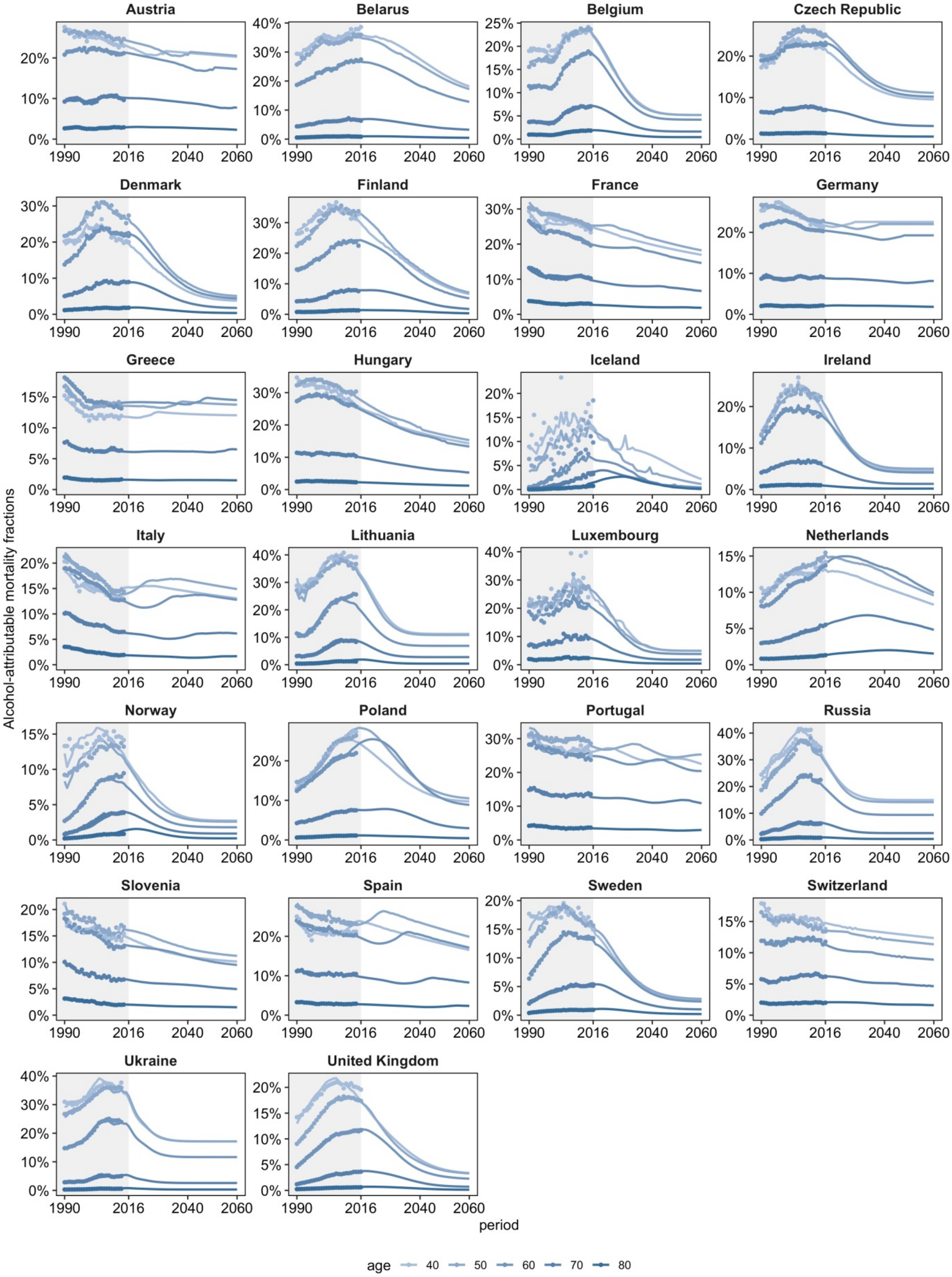


Figure 3 - Past and future trends in age-standardised alcohol-attributable mortality fractions (20-84), 1990-2060, for the 26 European countries compared (by country group*), by sex

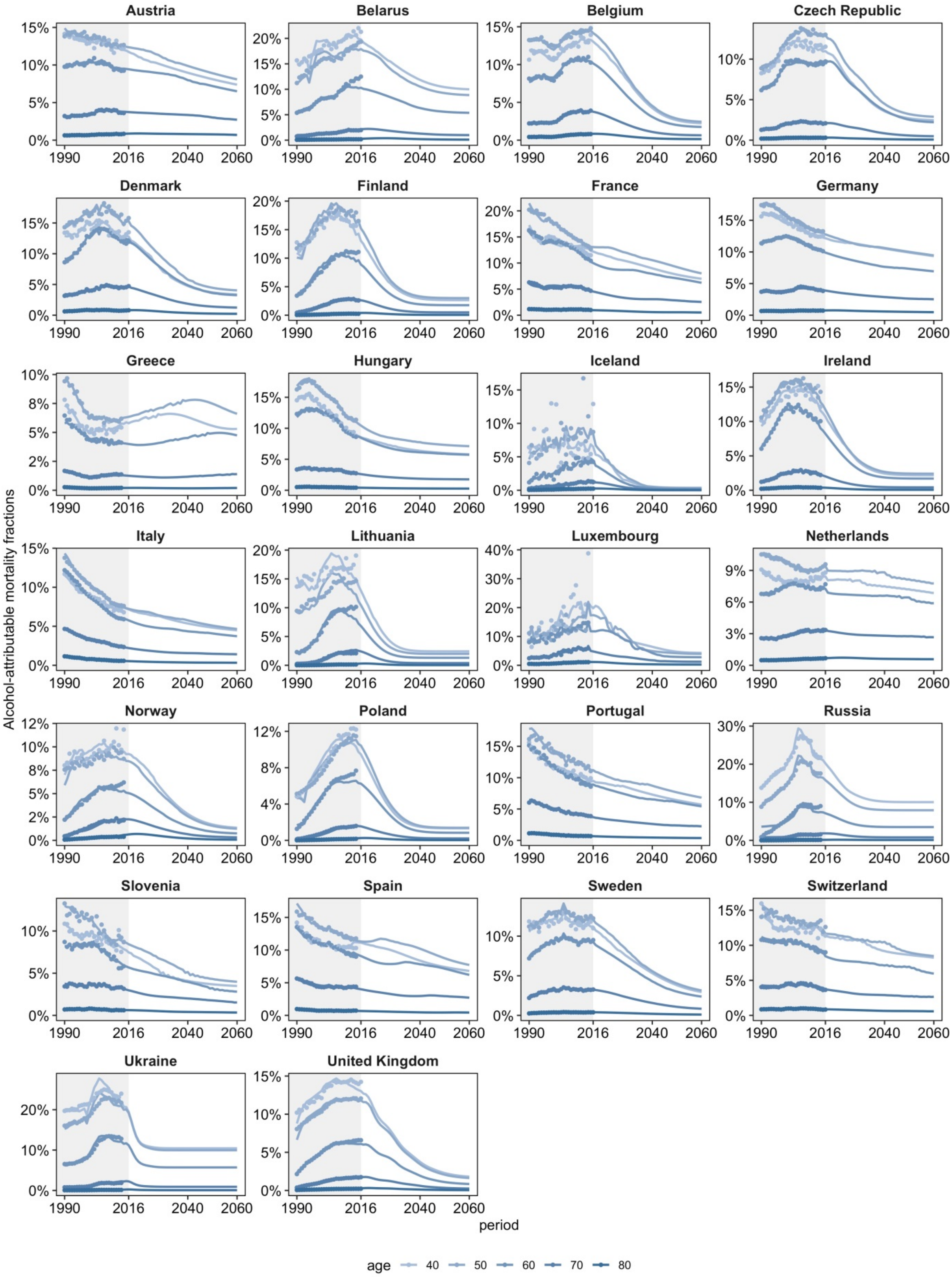


* In line with the past trends (see Figure 1), we divided the countries into three country groups:
1) Non-Eastern European countries with (decelerating) declines: Austria, France, Germany, Greece, Italy, Portugal, Spain, Switzerland
2) Remaining non-Eastern European countries: Belgium, Denmark, Finland, Iceland, Ireland, Luxembourg, Netherlands, Norway, Sweden, United Kingdom
3) Eastern European countries: Belarus, Czech Republic, Hungary, Lithuania, Poland, Russia, Slovenia, Ukraine
….

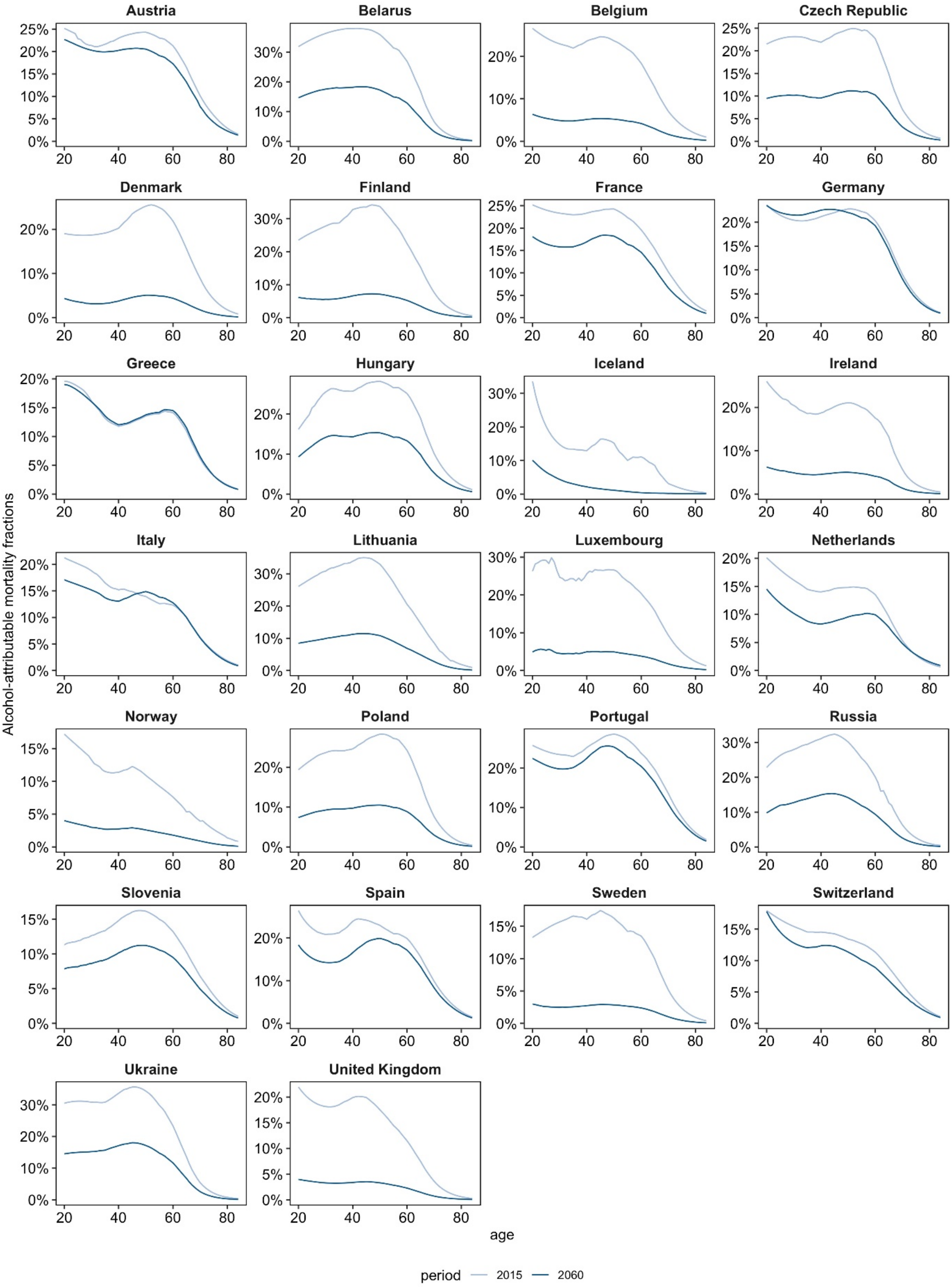
Appendix Figure 1a - Past and future age-specific alcohol-attributable mortality fractions, 1990-2060, 26 European countries, by country, men



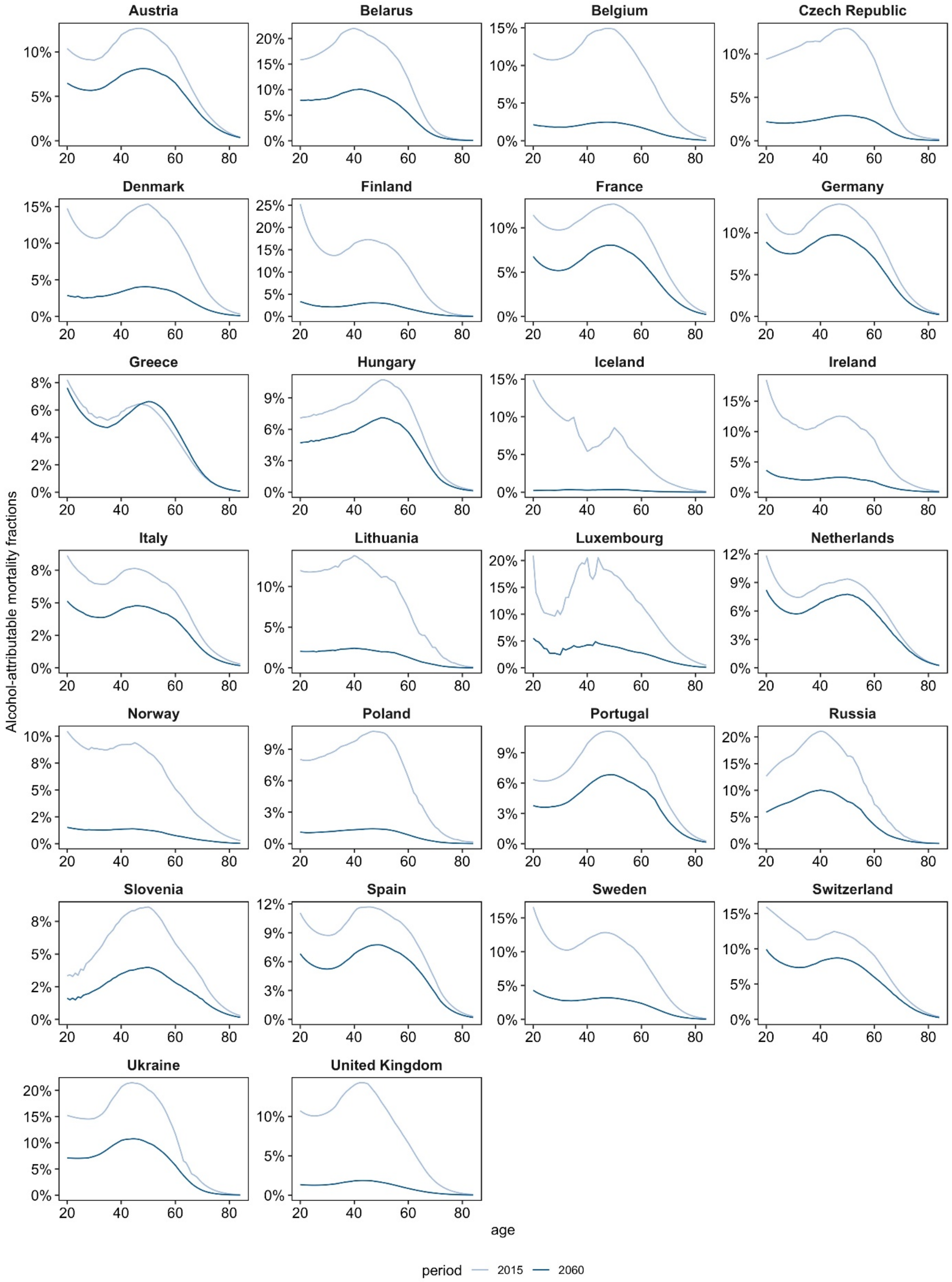
Appendix Figure 1b - Past and future age-specific alcohol-attributable mortality fractions, 1990-2060, 26 European countries, by country, women



Appendix Figure 2a - Current and future age patterns of the alcohol-attributable mortality fractions, 26 European countries, by country, men



Appendix Figure 2b - Current and future age patterns of the alcohol-attributable mortality fractions, 26 European countries, by country, women



Appendix Table 1 – Countries and years used in the analysis

Country	Start year	End year	First cohort year*	Last cohort year*
Austria	1990	2014	1906	1994
Belarus	1990	2016	1906	1996
Belgium	1990	2015	1906	1995
Czech Republic	1990	2016	1906	1996
Denmark	1990	2016	1906	1996
Finland	1990	2015	1906	1995
France	1990	2015	1906	1995
Germany	1990	2015	1906	1995
Greece	1990	2013	1906	1993
Hungary	1990	2014	1906	1994
Iceland	1990	2016	1906	1996
Ireland	1990	2014	1906	1994
Italy	1990	2014	1906	1994
Lithuania	1990	2014	1906	1994
Luxembourg	1990	2014	1906	1993
Netherlands	1990	2016	1906	1996
Norway	1990	2014	1906	1994
Poland	1990	2014	1906	1994
Portugal	1990	2015	1906	1995
Russia	1990	2014	1906	1994
Slovenia	1990	2014	1906	1994
Spain	1990	2014	1906	1994
Sweden	1990	2016	1906	1996
Switzerland	1990	2016	1906	1996
Ukraine	1990	2013	1906	1993
United Kingdom	1990	2016	1906	1996

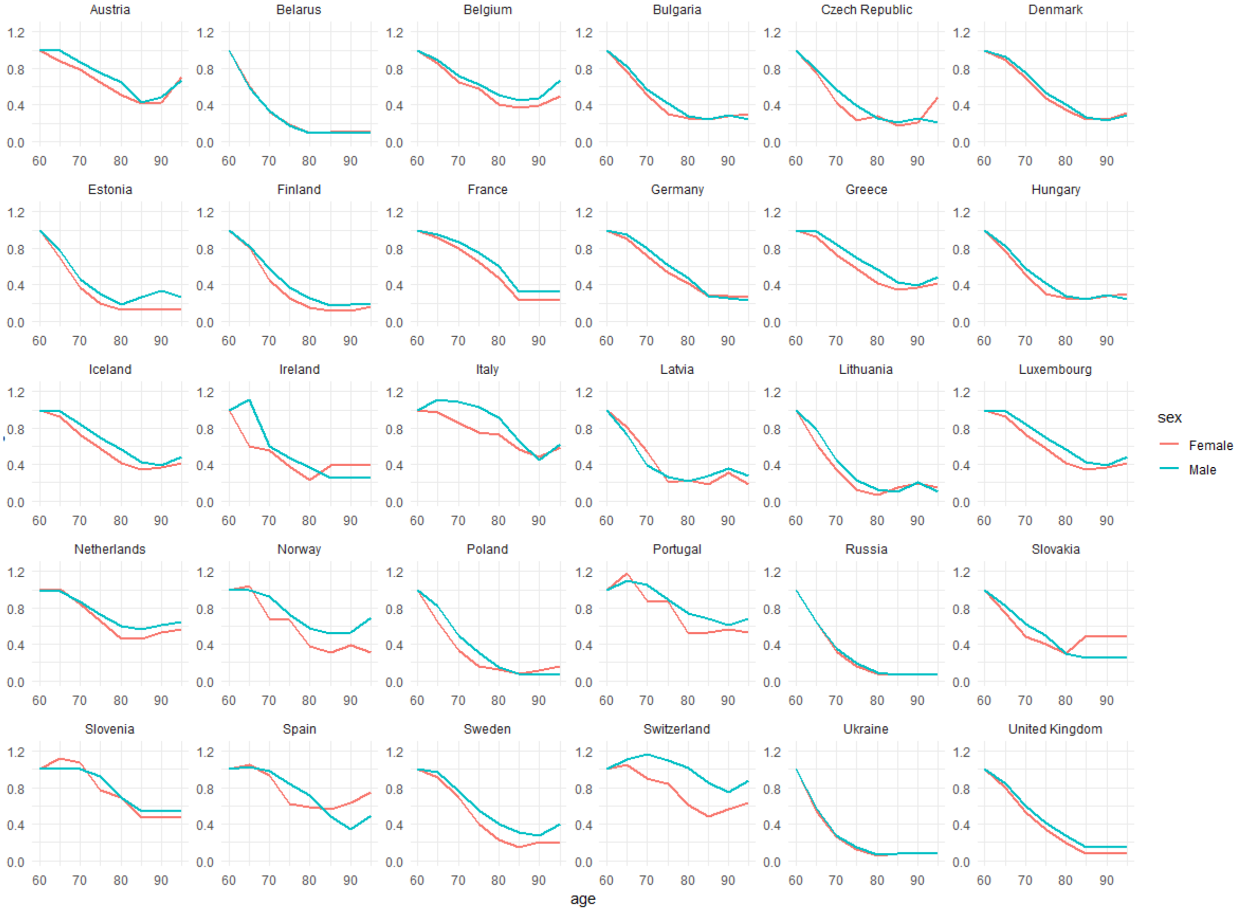
* Before burning the outer cohorts.

Past and future alcohol-attributable mortality in Europe - Supplementary information

Estimation of alcohol-attributable mortality

We obtained estimated alcohol-attributable mortality rates by sex, five-year age groups (20-24, …, 80-84) and single calendar year (1990-2016) from the Global Burden of Disease (GBD) Study 2017 (Stanaway et al. 2018; IHME 2019) for 30 European countries (= the countries in the final sample plus Bulgaria, Estonia, Latvia, and Slovakia).
These GBD estimates include both the deaths from causes of death wholly related to alcohol, as well as an estimate of the alcohol-related deaths from causes of death partly related to alcohol, thereby using information on alcohol consumption and relative risks of dying at different levels of drinking (Stanaway et al. 2018; IHME 2019). As such these estimates can better reflect true alcohol-attributable mortality levels compared to estimates from mere cause of death approaches that either include or exclude all deaths from causes that are only partly related to alcohol (e.g., external causes of death).
However, the GBD estimates of alcohol-attributable mortality at the highest ages are considered implausible – either very high or negative - because of a strong dependence of the estimation technique on the limited information on alcohol use at these ages, a lack of age-specific RRs of dying at these ages, and more in general a lack of available evidence on the impact of alcohol on health at those ages (e.g. Trias-Llimós et al. 2018; Manthey & Rehm 2019).
Therefore, we adjusted the GBD estimates of alcohol-attributable mortality for 65+ by applying to them the age pattern for the highest ages (only their shape, not their level) observed for the main group of causes of death wholly attributable to alcohol, which is regarded as more realistic (Trias-Llimós et al. 2018).
For this purpose, we used cause-specific mortality data from the WHO Mortality Database (WHO 2018) for the years included in ICD-10. We obtained these data for the following wholly alcohol-related causes of death: 'mental and behavioural disorders due to use of alcohol', 'alcoholic liver disease', 'accidental poisoning by and exposure to alcohol', 'degeneration of nervous system due to alcohol', 'alcoholic polyneuropathy', 'alcoholic gastritis', 'alcohol-induced chronic pancreatitis', 'foetal alcohol syndrome', 'intentional self-poisoning and exposure to alcohol' and 'poisoning by and exposure to alcohol' (ICD-10 codes: F10, K70, X45, G312, G621, G721, I426, K292, K860, Q860, X65, and Y15), as identified by Semyonova et al. 2014.
Subsequently, we calculated ratios between the alcohol-attributable mortality rates based on the WHO data for the five-year age groups from ages 65-69 onwards and the respective rates at ages 60-64 for each country and sex, for all years combined (see Figure S1). We subsequently applied these ratios (which represent the age pattern at the highest ages) to the GBD alcohol-attributable mortality rate at ages 60-64 to obtain the adjusted alcohol-attributable mortality rates for ages 65-69 and older. For example, if for a given population alcohol-related mortality based on causes of death wholly related to alcohol was 20% lower at ages 70-74 than at ages 60-64, we multiplied the GBD alcohol-attributable mortality rates at ages 60-64 by 0.8 to obtain the adjusted alcohol-attributable mortality rate at ages 70-74. For country-years with data for age groups up to 85+ (France, United Kingdom), we applied the ratio for ages 85+ to the age groups 85-89, 90-94, and 95+.
For countries without ICD-10 data in the WHO Mortality Database (Belarus, Hungary, Russia, Ukraine) or with insufficient data from WHO (Iceland, Bulgaria, Greece, Luxembourg), we calculated and applied alternative ratios. That is, for Belarus, Russia and Ukraine we calculated and applied the ratios using the alcohol-related mortality data (ICD-10 codes: F10, K70, X45) that is available from the Human Cause of Death Database (2017). For the remaining countries not included in the HCDD, we used the average WHO weights over the western European countries in our analysis for Greece, Luxembourg and Iceland, and the average WHO weights over the Eastern European countries in our analysis for Bulgaria and Hungary.

Figure S1 – Sex- and age-specific ratios used to adjust the age patterns for ages 65+ in the GBD data, based on alcohol-attributable cause-specific mortality data (WHO; Human Cause of Death Database)



Even after this adjustment we ended up with negative age-specific alcohol-attributable mortality rates at the (very) old ages, particularly in Estonia, Latvia and Slovakia, which we did not consider likely, in line with the literature disputing the (cardio)protective effects of alcohol on mortality (e.g. Holmes et al. 2014). Consequently, we excluded Estonia, Latvia, and Slovakia from our analysis, and we conducted our final analysis on the ages 20-84.

See Appendix S1 for a comparison of our age-specific and age-standardised alcohol-attributable mortality estimates with the GBD estimates.

The resulting age-specific alcohol-attributable mortality rates (20-24, 25-29, …, 80-84) by sex, country, and year (1990-2016) were divided by the respective all-cause mortality rates from the Human Mortality Database (2018) in order to obtain the alcohol-attributable mortality fractions by five-year age groups. Because for Bulgaria, data from the Human Mortality Database were only available up until 2010, we decided to exclude Bulgaria from our analysis as well.

To obtain estimates of alcohol-attributable mortality fractions by single year of age, we applied Loess smoothing (span = 0.5; degree = 2) to the log-transformed fractions by five-year age groups, after carefully considering other smoothing approaches.

To obtain an estimate of alcohol-attributable mortality fractions across the adult ages ($AAMF_{s,t}$) that could be compared over time (both over the past and into the future), we applied direct age standardisation. We standardised the smoothed $AAMF_{x,s,t}$ using the population-specific age distribution of deaths in 2010. The latter information was also obtained from the Human Mortality Database (2018).

Details behind the projection methodology

Age-period-cohort modelling

To project age-specific alcohol-attributable mortality fractions up to 2060, we employed an advanced age-period-cohort projection methodology. As the basis, we utilized the age-period-cohort modelling approach by Clayton and Schifflers (1987). This approach deals with the linear dependency between period and birth cohort (age = period – cohort) by decomposing mortality into the shared linear trend between period and cohort (= drift), a non-linear period effect, and a non-linear cohort effect. To simplify the interpretation and the projection, we clubbed the drift with the non-linear period effect using the Cairns et al. (2009) approach, which is implemented in the Stochastic Mortality Modelling (StMoMo) package (Villegas et al. 2015) in R. More specifically, this comprised the application of a set of constraints to – in our case – the cohort parameter. Thus, our period parameter captures the entire linear time trend (= includes the drift), while the cohort parameter captures the cohort variations from this overall trend. This approach results in a period parameter that is largely in line with the age-standardised AAMF, and a cohort parameter that is still relatively easy to interpret.

In applying the age-period-cohort model to the age-specific alcohol-attributable mortality fractions (AAMF), we used a generalised logit as the link function. The logit transformation ensured future AAMFs between zero and one, and and enabled us to project (eventually) declining AAMF for selected countries with currently increasing AAMF, in line with our general projection approach. In addition, we generalised the APC model to include more restricted lower bounds of the projected fractions and their projection intervals (PIs), in order to avoid unrealistic crossovers between men and women and between countries.

The final model we applied for each country, by sex, is:

$$logit\left(\frac{AAMF_{x,t} - LB_x}{UB_x - LB_x}\right) = \tilde{\alpha}_x + \tilde{\kappa}_t + \tilde{\gamma}_{t-x} .$$

where $AAMF_{x,t}$ are smoothed alcohol attributable mortality fractions by single years of age (x) and year (t). LB_x stands for the age-specific lower bounds, which are constant over time but differ by population (see below). UB_x stands for the age-specific upper bounds, which we set to one for all populations and time periods. The transformed parameters $\tilde{\alpha}_x$, $\tilde{\kappa}_t$, and $\tilde{\gamma}_{t-x}$ capture the age pattern, the overall time trend (period), and the cohort-specific deviations from the time trend, respectively.

Age-specific lower bounds and age-standardised lower limits

We imposed age-specific lower bounds for each population on the basis of assumed lower limits to age-standardised AAMF. That is, we assumed that in the future, the age-standardised AAMF would remain higher for men than for women, whom historically always exhibited (much) lower AAMF levels. Similarly, based on past observations, we consider it unlikely that among men, the (much) higher current age-standardised AAMF values in Eastern European countries would become lower in the future than those in Western European countries. For this reason, we selected different lower limits of age-standardised AAMF for different groups of countries, and obtained the age-specific lower bounds by applying to these lower limits the population-specific age pattern observed in 2016/LAY.

More specifically, for the selection of the lower limit of age-standardised AAMF, we categorised the countries according to their past trends and their past (peak) levels of age-standardised AAMF. In selecting the actual lower limit per category of countries, we also had to keep in mind that the implementation of the resulting age-specific lower bounds can lead to the omission of past age-specific values when these past values are lower than the lower bound.

The past trends in age-standardised alcohol-attributable mortality fractions (AAMF) (Figure 1) clearly show that for men in selected non-Eastern European countries, the decline was stagnating at levels between approximately 5% and 10%. We do not expect that among men in Eastern European countries, AAMF levels will be lower than these stagnating levels. Therefore, we imposed a lower age-

standardised AAMF limit of 5% in Eastern European countries with a high peak (Czech Republic, Hungary, Lithuania, Poland, and Slovenia). For Belarus, Russia, and Ukraine, where very high peak levels are observed, we imposed a lower limit of 7.5%.
For men in the countries with (decelerating) declines (France, Portugal, Germany, Switzerland, Austria, Greece, Spain, Italy), we selected a largely symbolic lower limit of 1.5% (three times as high as the lower bound for women)(see below). In practice, future AAMF levels (up to 2060) are projected to fall below 5% for Switzerland only (4.9%).
For men in the remaining non-Eastern European countries with either an increase followed by a decline, or a (decelerating) increase, a clear distinction can be made between countries with an (expected) low peak (Norway, UK, Sweden, Iceland), and countries with an (expected) high peak (Belgium, Denmark, Finland, Luxembourg, Ireland); with the Netherlands in between. For the first group, we selected a lower bound of one (although for Iceland, we had to adjust the lower limit slightly downwards to avoid omitting too many past observations). This lower limit was chosen because a level below 1.5% was already observed among men in Iceland in 1990. For men in the countries with an (expected) high peak, we selected a lower limit of 2%, because the observed past peaks in these countries were generally twice as high as those in the countries with observed low peaks. For men in the Netherlands, we selected a lower limit of 1.5%.

For women, stagnation of AAMF was clearly evident only in Greece, at a level of 1%. Therefore, for women in the countries that currently display (decelerating) declines (France, Portugal, Germany, Switzerland, Spain, Italy, Austria), we set a lower limit of 1%. For Greece, implementing lower bounds proved unnecessary.
The differences in AAMF levels between Eastern and Western Europe were much smaller for women than for men, with crossovers already clearly visible. Therefore, for women in the countries with a trend in age-standardised AAMF that is generally increasing, we selected the lower limits that were more in line with the observed differences in the (expected) peak in AAMF. Particularly for women in Western Europe, we took into account the lowest AAMF levels already observed (in Iceland, at < 1%), and the current differences between men and women in the AAMF levels.
For women in Iceland, who exhibit a very low peak, we set the lower limit at 0.075%, which represents half the value of the lower bound set for men in Iceland. For women in countries with an (expected) low peak (Norway, United Kingdom, Poland) we set the lower limit at 0.33%. For Norway and the UK, this level represents one-third of the value of the lower limit selected for men in these countries. For women in countries with (expected) average peak values (Czech Republic, Belgium, Lithuania, the Netherlands, Sweden, Finland, and Ireland) we set a lower limit of 0.66%. For the non-Eastern European countries, this limit is between 1.5 and three times lower than the lower limit for men in the respective countries. For Lithuania, implementing this lower limit proved problematic; therefore, we reduced the lower limit to 0.5%. For women in Western European countries with very high (expected) recent peak values (Denmark, Luxembourg), we set a lower limit of 1.25%, which is 1.6 times lower than the lower limit set for men in these countries, and is two times higher than the lower limit set for the Western European countries with average peak values (which is approximately in line with the differences in observed peak values). For women in Eastern European countries with very high (expected) recent peak values (Belarus, Hungary, Russia, Ukraine), we set the lower limit slightly higher, at 2.0%, to ensure that the differences between men and women in these countries do not become too large in the future.

See Table S1 for the categorisation of the countries according to their past trends in age-standardised AAMF(20-84) and the lower limits we selected by sex and country group.

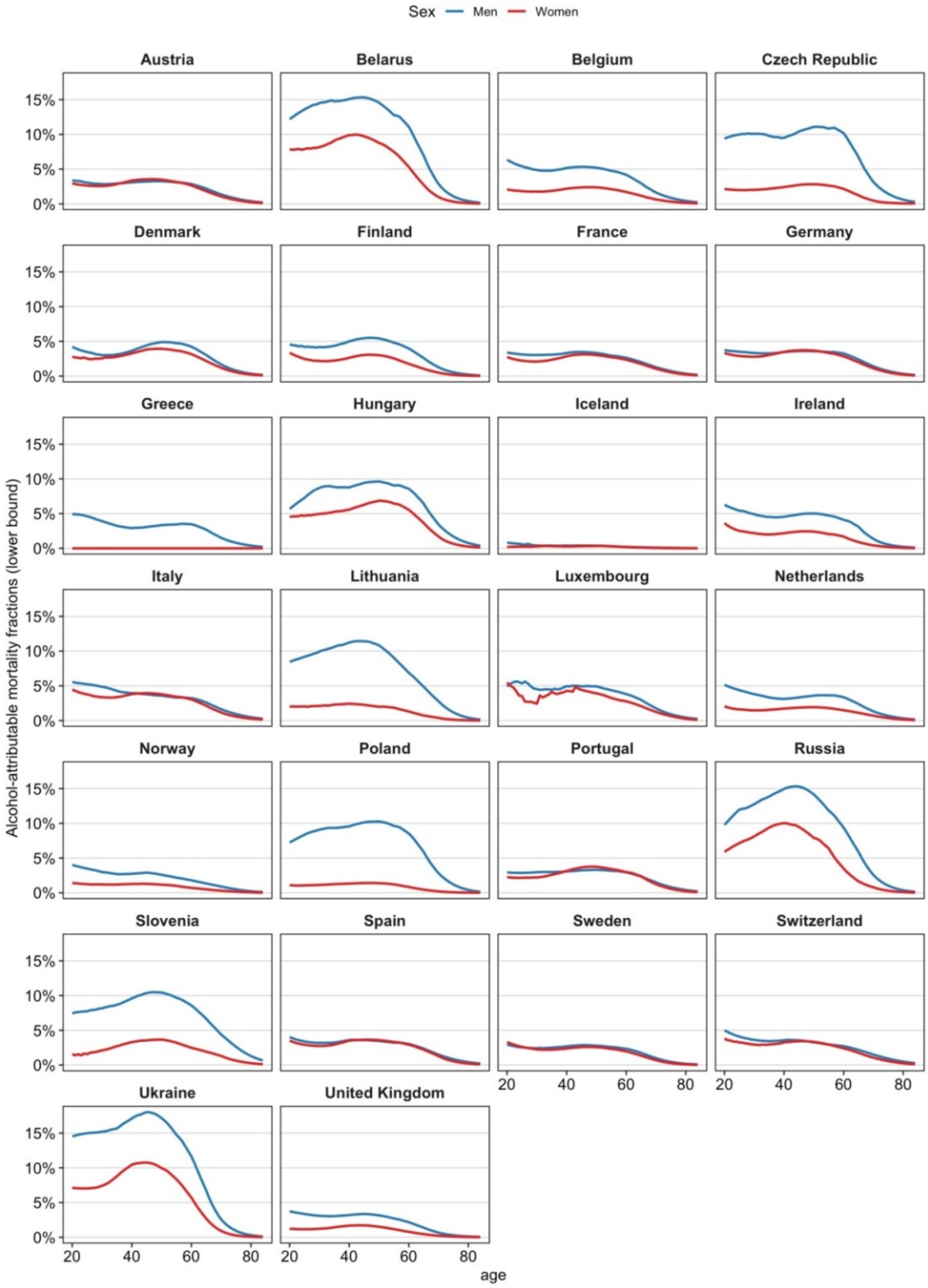
Table S1 Categorisation of countries and the selected lower limits of the age-standardised alcohol-attributable mortality fractions (20-84)

	Men			Women	
Country	Categorization past trend	Lower limit		Categorization past trend	Lower limit
Austria	(decelarating) decline	1.50%		(decelarating) decline	1.00%
France	(decelarating) decline	1.50%		(decelarating) decline	1.00%
Germany	(decelarating) decline	1.50%		(decelarating) decline	1.00%
Greece	(decelarating) decline	1.50%		(decelarating) decline	0.00%
Italy	(decelarating) decline	1.50%		(decelarating) decline	1.00%
Portugal	(decelarating) decline	1.50%		(decelarating) decline	1.00%
Spain	(decelarating) decline	1.50%		(decelarating) decline	1.00%
Switzerland	(decelarating) decline	1.50%		(decelarating) decline	1.00%
Iceland	Low Peak	0.13%		Low Peak	0.08%
Norway	Low Peak	1.00%		Low Peak	0.33%
Sweden	Low Peak	1.00%		Average Peak	0.66%
United Kingdom	Low Peak	1.00%		Low Peak	0.33%
Netherlands	Middle Peak	1.50%		Average Peak	0.66%
Belgium	Average Peak	2.00%		Average Peak	0.66%
Denmark	Average Peak	2.00%		High Peak (West)	1.25%
Finland	Average Peak	2.00%		Average Peak	0.66%
Ireland	Average Peak	2.00%		Average Peak	0.66%
Luxembourg	Average Peak	2.00%		High Peak (West)	1.25%
Czech Republic	High Peak	5.00%		Average Peak	0.66%
Hungary	High Peak	5.00%		High peak (East)	2.00%
Lithuania	High Peak	5.00%		Average Peak	0.50%
Poland	High Peak	5.00%		Low Peak	0.33%
Slovenia	High (past) peak	5.00%		(decelarating) decline	1.00%
Belarus	Very High Peak	7.50%		High Peak (East)	2.00%
Russia	Very High Peak	7.50%		High Peak (East)	2.00%
Ukraine	Very High Peak	7.50%		High Peak (East)	2.00%

Age-specific lower bounds were obtained by applying the population-specific age pattern (ages 20-84) observed in the LAY to these lower limits. More specifically, we linearly transformed the population-specific age pattern observed in the LAY so that it would equal the value of the selected population-specific lower limit of the age-standardised AAMF. We did so by dividing, for each age, the age-specific AAMF by the ratio of the actual AAMF20-84 to the desired lower limit of AAMF20-84.

See Figure S2 for the age-specific lower bounds we implemented.

Figure S2. Age-specific lower bounds we implemented, by sex



Projection of the parameters

For the projection of the period (k_t) and cohort (g_c) parameters, which we obtained from the application of our APC model to our data, we employed different strategies (see Box S1) for countries with different past trends in k_t and g_c (see Figure S3-S4).

We projected the (recent) trend in the period and cohort parameters mainly using stochastic time-series forecasting (ARIMA). ARIMA(p,d,q) models are a very general class of time-series models for forecasting future values based on past observed values, in which *p* denotes the order of the auto-regressive model (= how many previous time points of the time-series to use in the auto-regression), *d* is the degree of differencing required to obtain a stationary time-series, and q is the order of the moving-average model (= the lag of the error component) (Box et al. 2015). We selected the best-fitting ARIMA model subject to some constraints, based on minimum *AICc* (Akaike Information Criterion), using the forecast package in R (Hyndman et al. 2019).

However, for populations with a trend in age-standardised AAMF that is generally increasing, we extrapolated the period parameter deterministically by means of a quadratic curve. That is, a quadratic curve in the logit of fractions will result in a wave pattern in the normal fractions. Consequently, the resulting projections are in line with the idea of a wave-shaped epidemic, as observed for alcohol in other countries and for smoking in all European countries.

Box S1 - Strategy for the projection of the period and cohort parameters based on their past trends

Past trend	**Projection strategy**
Period parameter (k_t)	
Continued decline (N = 6)	Projection decline by best ARIMA (p<=3, d=1, q<=3) with drift for whole period
Deceleration of decline (N = 8)	Projection recent decline by best ARIMA (p<=3, d=1, q<=3) with drift for year since trend break
Decline with recent stagnation (N = 6)	Projection recent trend by best ARIMA (p<=3, d=1, q<=3) with drift. If recent increase, project stable level by ARIMA (0,1,0) without drift.
Increase with recent decline (N = 26)	Quadratic over whole period
Increase without recent decline (N = 6)	Quadratic over period that shows the best fit
Cohort paramater (g_c)	
Reversed U-shape without recent stagnation (N = 17)	Recent downward trend extrapolation by best ARIMA (p<=3,d=1,q<=3) model with drift
Reversed U-shape with recent stagnation (N = 17)	Recent trend extrapolation (best ARIMA (p<=3, d, q <=3)); when increase => stable trend by ARIMA (0,1,0) with no drift
Recent decline (N = 5)	Recent downward trend extrapolation by best ARIMA (p<=3,d=1,q<=3) model with drift
Fluctuating trend (N = 10)	Mean reverting process around zero by best ARIMA (p<=3,0,q<=2) with zero mean on whole trend
U-shaped (N = 3)	ARIMA (0,1,0) without drift on whole trend

In performing the projections for k_t and g_c, we made sure we were not selecting two very different ARIMA models, in cases in which the past trends in one country looked rather similar for men and women. Moreover, we made sure that there was no resulting long-term divergence between the fractions for men and women.

To ensure more robust estimates and to diminish the projection intervals, we applied the projections to the longest observation window possible: i.e., either the whole time-series if there was no change in the trend, or the trend from a certain trend break.

Figure S3 Past trend period parameter (k_t) for the different countries, according to group

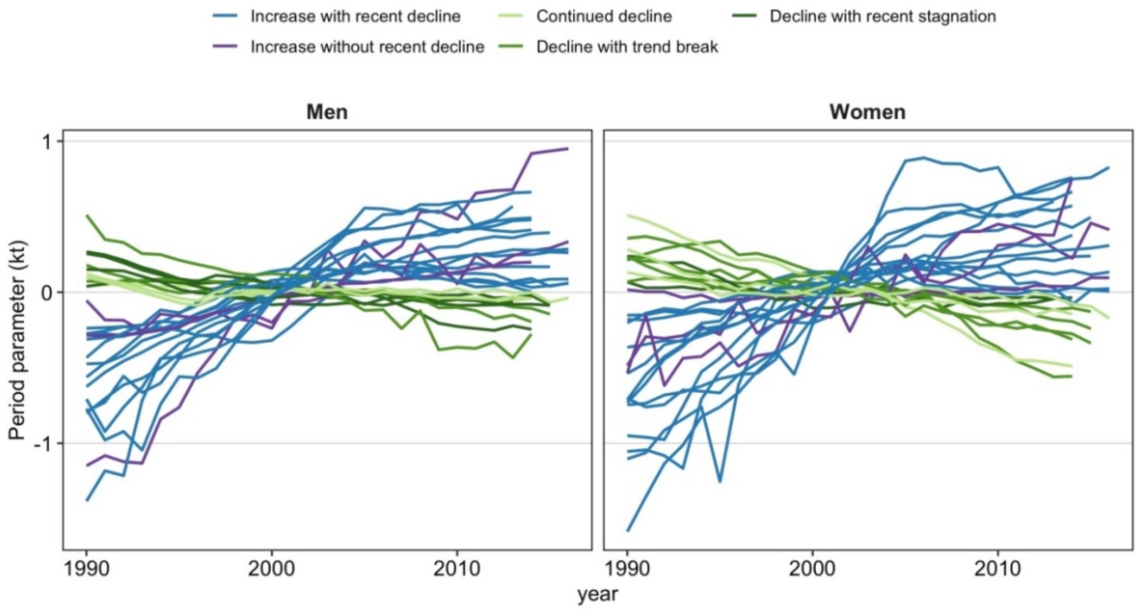
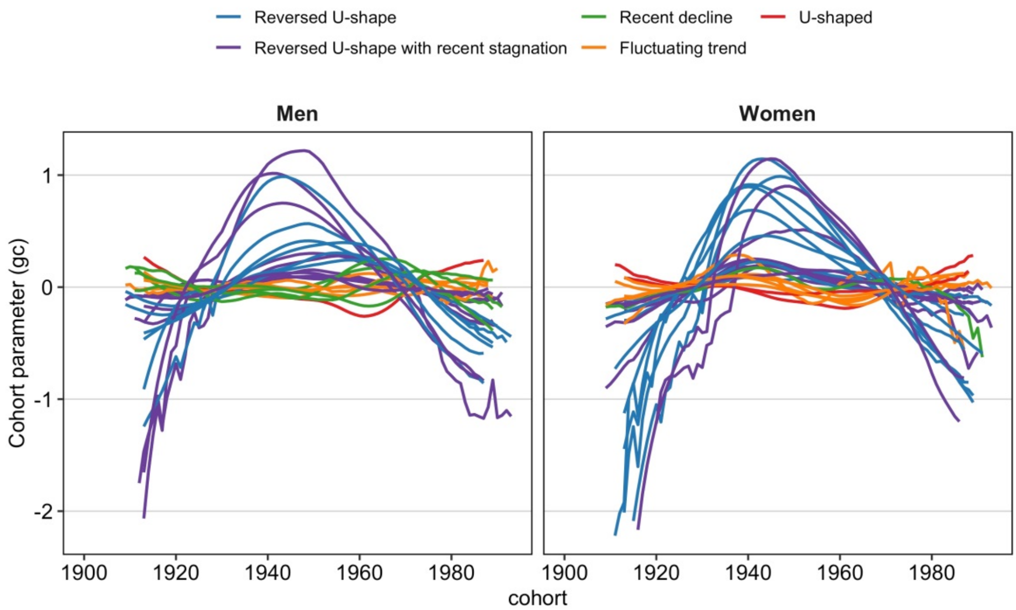


Figure S4 Past trend cohort parameter (g_c) for the different countries compared, according to group



Projection of the period parameter

The period parameter (k_t) is projected into the future by a quadratic curve with correlated errors for populations with predominantly increasing k_t trends, and, for populations in which these trends are mainly declining, by extrapolation of the decline by the best-fitting ARIMA (Auto Regressive Integrated Moving Average) model (p<=3,d=1,q<=3) with drift, based on minimum AICc (Akaike Information Criterion). For populations in which the decline in k_t is followed by a recent increase, we implemented a stable future k_t trend using an ARIMA(0,1,0) without drift.

More specifically, we divided the k_t trends into five categories (see Figure S3) and devised for each of these categories a different projection model to optimally extrapolate the past trend observed.

1) **Continued decline.** For countries with a decline and without a clear trend break in k_t, use the best ARIMA (p, d=1, q) model (according to AICc) for the whole period from the start of the decline, thereby enforcing a drift, and maximum p and q = 3.
2) **Decline with trend break.** For countries with a decline that is not constant, use the best-fitting ARIMA (p, d=1, q) model (according to AICc) for the period that best depicts the recent decline, thereby enforcing a drift, and maximum p and q = 3.
3) **Decline with recent stagnation.** For those countries with a decline with a recent stagnation (deceleration / level / recent increase), project the trend from the break with the best ARIMA (p,1,q) model with drift (according to AICc). If there is a recent increase, enforce a stable trend by applying ARIMA (0,1,0) with no drift over the period with the recent increase.
4) **Increase with recent decline.** For populations with increasing trends in k_t, but with a recent trend break, a quadratic model is used from the start of the increase (mostly the whole period).
5) **Increase without recent decline**. For populations with increasing trends in k_t, but without a recent trend break, a bell-shaped quadratic model is used over the period that best fits the data.

See Table S2 for the specifics of the period projection by country and sex.

Table S2 – Specifics period projection

Population	Trend description kt	Projection principle kt	First year	Last year	Modelling of errors for the quadratic projections / Final kt model for the remaining projections
Belarus_Female	Increasing with decelerating increase	quadratic	1990	2016	Error model: ARIMA(1,0,0) with zero mean
Belarus_Male	Increasing from 1991 with recent stagnation	quadratic	1991	2016	Error model: ARIMA(1,0,0) with zero mean
Belgium_Female	Increasing from 2000 with decelerating increase	quadratic	2000	2015	Error model: ARIMA(1,0,0) with non-zero mean
Belgium_Male	Increasing from 2000 with decelerating increase	quadratic	2000	2015	Error model: ARIMA(0,0,1) with zero mean
Czech Republic_Female	Increasing with recent decline	quadratic	1990	2016	Error model: ARIMA(2,0,1) with zero mean
Czech Republic_Male	Increasing from 1995 with recent decline	quadratic	1995	2016	Error model: ARIMA(1,0,0) with zero mean
Denmark_Female	Increasing with recent decline	quadratic	1990	2016	Error model: ARIMA(1,0,0) with zero mean
Denmark_Male	Increasing with recent decline	quadratic	1990	2016	Error model: ARIMA(1,0,0) with zero mean
Finland_Female	Increasing from 1992 with stagnation	quadratic	1992	2015	Error model: ARIMA(1,0,0) with zero mean
Finland_Male	Increasing with stagnation	quadratic	1990	2015	Error model: ARIMA(1,0,0) with zero mean
Ireland_Female	Increasing with recent decline	quadratic	1990	2014	Error model: ARIMA(1,0,0) with non-zero mean
Ireland_Male	Increasing with recent decline	quadratic	1990	2014	Error model: ARIMA(1,0,0) with non-zero mean
Lithuania_Female	Increasing from 1992; change increase 1998; recent stagnation	quadratic	1999	2014	Error model: ARIMA(1,0,0) with zero mean
Lithuania_Male	Increasing from 1993; change increase 1997; decelerating increase	quadratic	1997	2014	Error model: ARIMA(1,0,0) with zero mean
Norway_Female	Increasing with decelerating increase	quadratic	1990	2014	Error model: ARIMA(1,0,0) with zero mean
Norway_Male	Increasing from 1991 with decelerating increase	quadratic	1991	2014	Error model: ARIMA(1,0,0) with non-zero mean
Poland_Female	Increasing from 1993 with decelerating increase	quadratic	1993	2014	Error model: ARIMA(0,0,2) with zero mean
Poland_Male	Increasing with decelerating increase	quadratic	1990	2014	Error model: ARIMA(1,0,0) with zero mean
Russia_Female	Increasing with recent decline	quadratic	1990	2014	Error model: ARIMA(2,0,0) with zero mean
Russia_Male	Increasing with recent decline	quadratic	1990	2014	Error model: ARIMA(0,0,1) with zero mean
Sweden_Female	Increasing with recent decline	quadratic	1990	2016	Error model: ARIMA(0,0,1) with zero mean
Sweden_Male	Increasing with recent decline	quadratic	1990	2016	Error model: ARIMA(1,0,0) with zero mean
Ukraine_Female	Increasing; change increase 1999; recent stagnation	quadratic	1999	2013	Error model: ARIMA(2,0,0) with zero mean
Ukraine_Male	Increasing; change increase 1998; recent decelerating increase	quadratic	1998	2013	Error model: ARIMA(2,0,0) with zero mean
United Kingdom_Female	Increasing with decelerating increase	quadratic	1990	2016	Error model: ARIMA(2,0,0) with zero mean
United Kingdom_Male	Increasing with decelerating increase	quadratic	1990	2016	Error model: ARIMA(2,0,0) with zero mean
Iceland_Female	Continued increase	quadratic enforced	2002	2014	Error model: ARIMA(1,0,0) with non-zero mean
Iceland_Male	Continued increase	quadratic enforced	1990	2016	Error model: ARIMA(1,0,0) with non-zero mean
Luxembourg_Female	Continued increase from 1992	quadratic enforced	1999	2013	Error model: ARIMA(1,0,0) with non-zero mean
Luxembourg_Male	Continued increase from 2000	quadratic enforced	2000	2014	Error model: ARIMA(1,0,0) with non-zero mean
Netherlands_Female	Continued increase from 1995	quadratic enforced	1995	2011	Error model: ARIMA(1,0,0) with zero mean
Netherlands_Male	Continued increase	quadratic enforced	1995	2015	Error model: ARIMA(2,0,0) with zero mean
Austria_Male	Decreasing without trend break	decline	1990	2014	Kt model: ARIMA(0,1,0) with drift
Italy_Female	Decreasing without trend break	decline	1990	2014	Kt model: ARIMA(0,1,0) with drift
Spain_Female	Decreasing without trend break	decline	1990	2014	Kt model: ARIMA(0,1,0) with drift
Spain_Male	Decreasing without trend break	decline	1990	2014	Kt model: ARIMA(0,1,0) with drift
Switzerland_Female	Decreasing without trend break	decline	1990	2016	Kt model: ARIMA(0,1,0) with drift
Switzerland_Male	Decreasing without trend break	decline	1990	2016	Kt model: ARIMA(0,1,0) with drift
France_Female	Decreasing with trend break in 1998, still decline	recent decline	1998	2015	Kt model: ARIMA(0,1,0) with drift
France_Male	Decreasing with trend break in 1998, still decline	recent decline	1998	2015	Kt model: ARIMA(0,1,0) with drift
Germany_Female	Decreasing with trend break in 1993, still decline	recent decline	1993	2015	Kt model: ARIMA(0,1,0) with drift
Hungary_Female	Decreasing with trend break in 2004, still decline	recent decline	2004	2014	Kt model: ARIMA(0,1,0) with drift
Hungary_Male	Decreasing with trend break in 2006, still decline	recent decline	2006	2014	Kt model: ARIMA(0,1,0) with drift
Portugal_Female	Decreasing with trend break in 1999 and 2001, still decline	recent decline	2001	2015	Kt model: ARIMA(1,1,0) with drift
Slovenia_Female	Decreasing with trend break in 2001, still decline	recent decline	2001	2014	Kt model: ARIMA(1,1,0) with drift
Slovenia_Male	Decreasing with trend break at 2002, still decline	recent decline	2002	2014	Kt model: ARIMA(0,1,0) with drift
Austria_Female	Decreasing with trend break at 1999, no more decline	recent trend	1999	2014	Kt model: ARIMA(0,1,0)
Germany_Male	Decreasing with trend break in 2010, no more decline	recent trend	2010	2015	Kt model: ARIMA(0,1,0)
Greece_Female	Decreasing with trend break in 2000, no more decline	recent trend	2000	2013	Kt model: ARIMA(0,1,0)
Greece_Male	Decreasing with trend break in 2000, no more decline	recent trend	2000	2013	Kt model: ARIMA(0,1,0)
Italy_Male	Decreasing with trend break in 2009, deceleration	recent trend	2009	2014	Kt model: ARIMA(0,1,0) with drift
Portugal_Male	Decreasing with trend break in 1995, deceleration	recent trend	1995	2015	Kt model: ARIMA(0,1,0) with drift

Projection of the cohort parameter

We based the projection of the gamma parameter (g_c) on the trend after omitting (=burning) the outer cohorts to ensure stable trends. To decide how many cohorts to omit/burn we performed a statistical test. That is, by employing a t-test to the cohort parameter, we assessed which cohorts did not differ from zero at a statistical significance level (p) of 0.05. In principle, we burned the first and last five cohorts. However, if the statistical test (i.e., burn cohorts with $p > 0.05$) indicated that only the last three cohorts were not statistically significant from zero, we burned the first and last three cohorts. If the statistical test indicated that seven or more of the last cohorts were not statistically significant from zero, we burned the first and last seven cohorts. For women in Iceland, we burned the six last cohorts, and for men in Greece, we burned the last seven cohorts; thereby deviating from the outcomes of the statistical procedure.
See Table S3 for the N of the outer cohorts that we omitted (=burned) in the end.

Following a close inspection of the trends in g_c after burning the cohorts, we assigned the countries to five different groups (see Figure S4). For each group of countries, we employ a different main strategy. However, these strategies all boil down to the same approach: i.e., the recent trend is extrapolated as much as possible by means of the best-fitting (constrained) ARIMA model. When this leads to an increase, we enforced a stable trend using ARIMA(0,1,0) with no drift.

1. **Reversed U-shape (=bell shaped).** For those populations in which the cohort parameter showed a reversed U-shape without a recent stagnation, we extrapolated the recent downward trend of g_c from a potential trend break by applying the best-fitting ARIMA (p<=3,d=1,q<= 3) model with drift.
2. **Reversed U-shape (= bell shaped) with recent stagnation.** For those populations in which the cohort parameter showed a reversed U-shape with a recent stagnation of the downward trend, we use a recent trend extrapolation of g_c applied to either the last 10 years (when stagnation <= five years before the first burned cohort) or the period since the stagnation (when stagnation > five years before the first burned cohort). We do so by applying the best-fitting ARIMA (p<=3, d, q <=3) model (no enforcement of drift). However, when this leads to an increase, we enforced a stable trend by using ARIMA (0,1,0) with no drift over the respective period.
3. **Recent decline.** For those populations in which the cohort parameter revealed a recent decline, we extrapolated the recent downward trend from a potential trend break by applying the best-fitting ARIMA (p<=3,d=1,q<= 3) model with drift.
4. **Fluctuating trend.** For those populations in which the cohort parameter fluctuates around zero, we extrapolated the fluctuating trend by a mean-reverting process around zero by applying the best-fitting ARIMA(p<=3, 0, q<=2) model with zero mean on the whole trend (after burning).
5. **U-shaped.** For those populations in which the cohort parameter revealed a U-shaped pattern, we projected by means of an ARIMA (0,1,0) without drift on the entire cohort trend (after burning).

We used the longest possible cohort trend in order to produce relatively small prediction intervals.

See Table S3 for the specifics of the cohort projection by country and sex.

Table S3 – Specifics cohort projection - organised according to g_c trend

Population	N burned outer cohorts	gc trend	gc principle	gc first year	gc last year	Final gc model
Austria_Female	7	bell shaped	Recent trend	1972	1987	ARIMA(0,1,0) with drift
Belarus_Female	7	bell shaped	Recent trend	1950	1989	ARIMA(1,1,0) with drift
Czech Republic_Female	7	bell shaped	Recent trend	1962	1989	ARIMA(3,1,0) with drift
Finland_Female	7	bell shaped	Recent trend	1943	1988	ARIMA(1,1,2) with drift
Finland_Male	3	bell shaped	Recent trend	1958	1992	ARIMA(2,1,2) with drift
Lithuania_Female	7	bell shaped	Recent trend	1949	1987	ARIMA(1,1,1) with drift
Netherlands_Female	3	bell shaped, deceleration from 1961	Recent trend	1961	1993	ARIMA(1,1,1) with drift
Netherlands_Male	3	bell shaped	Recent trend	1962	1993	ARIMA(2,1,0) with drift
Norway_Female	7	bell shaped	Recent trend	1946	1987	ARIMA(0,1,0) with drift
Norway_Male	7	bell shaped	Recent trend	1947	1987	ARIMA(1,1,0) with drift
Poland_Female	5	bell shaped	Recent trend	1945	1989	ARIMA(1,1,0) with drift
Sweden_Male	7	bell shaped	Recent trend	1953	1989	ARIMA(3,1,0) with drift
United Kingdom_Female	5	bell shaped	Recent trend	1948	1991	ARIMA(1,1,1) with drift
United Kingdom_Male	7	bell shaped	Recent trend	1961	1989	ARIMA(1,1,0) with drift
Denmark_Female	3	bell shaped	Recent trend	1947	1993	ARIMA(0,1,0) with drift
Denmark_Male	7	bell shaped	Recent trend	1960	1989	ARIMA(2,1,0) with drift
Lithuania_Male	7	bell shaped	Recent trend	1943	1987	ARIMA(1,1,3) with drift
Russia_Male	7	bell shaped; level/increase from 1986	Recent trend	1978	1987	ARIMA(0,2,0)
Iceland_Female	6	bell shaped; increase from 1988	Recent trend	1981	1990	ARIMA(0,1,0)
Russia_Female	7	bell shaped: level/increase from 1987	Recent trend	1978	1987	ARIMA(0,1,0)
Sweden_Female	7	bell shaped; level from 1987	Recent trend	1980	1989	ARIMA(0,1,0)
Ukraine_Female	7	bell shaped; deceleration from 1986	Recent trend	1977	1986	ARIMA(0,2,0)
Ukraine_Male	7	bell shaped; level from 1986	Recent trend	1977	1986	ARIMA(0,2,0)
Austria_Male	3	bell shaped; level/increasing from 1983	Recent trend	1983	1991	ARIMA(0,1,0)
Belarus_Male	7	bell shaped; increase from 1980	Recent trend	1980	1989	ARIMA(0,1,0)
Belgium_Female	3	bell-shaped; decelaration/level from 1979	Recent trend	1979	1992	ARIMA(0,1,0)
Belgium_Male	5	bell shaped; decelaration from 1984	Recent trend	1984	1990	ARIMA(0,1,0)
Germany_Female	7	bell shaped; increase from 1979	Recent trend	1979	1988	ARIMA(0,1,0)
Germany_Male	7	bell shaped; increase from 1979	Recent trend	1979	1988	ARIMA(0,1,0)
Hungary_Female	3	bell shaped; increase from 1974 (stable from 1985)	Recent trend	1974	1991	ARIMA(0,1,0)
Hungary_Male	3	bell shaped; increase/fluctuating from 1978 onwards	Recent trend	1978	1991	ARIMA(0,1,0)
Iceland_Male	3	bell shaped; level from 1984	Recent trend	1984	1993	ARIMA(0,1,0)
Ireland_Female	5	bell shaped; increase from 1974	Recent trend	1974	1989	ARIMA(0,1,0)
Switzerland_Male	7	bell shaped; increase/fluctuating from 1966 onwards	Recent trend	1966	1989	ARIMA(0,1,0)
Ireland_Male	5	recent decline (from 1967 onwards)	Recent trend	1967	1989	ARIMA(0,1,0) with drift
Poland_Male	5	recent decline (from 1969 onwards)	Recent trend	1969	1989	ARIMA(1,1,0) with drift
Slovenia_Female	3	recent decline (from 1975 onwards)	Recent trend	1975	1991	ARIMA(1,1,0) with drift
Slovenia_Male	3	recent decline (from 1974 onwards)	Recent trend	1975	1991	ARIMA(1,1,0) with drift
Spain_Male	5	recent decline (from 1976 onwards)	Recent trend	1976	1989	ARIMA(0,1,0) with drift
Czech Republic_Male	7	fluctuating around 0	Mean reverting process	1913	1989	ARIMA(2,0,2) with zero mean
France_Female	7	fluctuating around 0	Mean reverting process	1913	1988	ARIMA(2,0,1) with zero mean
France_Male	7	fluctuating around 0	Mean reverting process	1913	1988	ARIMA(2,0,0) with zero mean
Greece_Female	5	fluctuating around 0	Mean reverting process	1911	1988	ARIMA(2,0,2) with zero mean
Greece_Male	7	fluctuating around 0	Mean reverting process	1913	1986	ARIMA(1,0,2) with zero mean
Luxembourg_Female	7	fluctuating around 0	Mean reverting process	1913	1987	ARIMA(2,0,1) with zero mean
Luxembourg_Male	3	fluctuating around 0	Mean reverting process	1909	1990	ARIMA(2,0,1) with zero mean
Portugal_Male	7	fluctuating around 0	Mean reverting process	1913	1988	ARIMA(2,0,1) with zero mean
Spain_Female	7	fluctuating around 0	Mean reverting process	1913	1987	ARIMA(2,0,2) with zero mean
Switzerland_Female	3	fluctuating around 0	Mean reverting process	1909	1993	ARIMA(3,0,2) with zero mean
Italy_Female	5	u-shaped	Last values	1911	1989	ARIMA(0,1,0)
Italy_Male	7	u-shaped	Last values	1913	1987	ARIMA(0,1,0)
Portugal_Female	7	u-shaped	Last values	1913	1988	ARIMA(0,1,0)

Main outcomes

We projected age-specific and age-standardised alcohol-attributable mortality fractions (20-84) by sex, country, and year up to 2060 by means of medians and their 95% projection intervals by performing 50,000 simulations. Median age-standardised AAMF and their 95% projection intervals were obtained by age-standardising each sample path.

- **Simulations**

For the deterministic quadratic curve projections of the period parameter k_t, we obtained correlated errors and related prediction intervals by applying the best-fitting mean-reverting process to the errors (i.e., the difference between the observed and the fitted values). In doing so, we restricted p to maximally two, and q to maximally four. Also, we avoided the ARIMA(0,0,0) model, as this approach would not result in correlated errors. In these cases, we chose the best model (based on the AICc) out of two options: ARIMA(1,0,0) or ARIMA(1,0,1). See Table S2.

For each of the simulations, we projected the period and the cohort trends independently, which, together with the age pattern, formed a single forecast sample path. The point forecast of $AAMF_{x,s}$ was then given by the median over the generated 50,000 sample paths, and the 95% prediction intervals were obtained by calculating the appropriate quantiles. To construct the forecasts, we did not take into account the parameter uncertainty in the age, period, and cohort parameters (a_x, k_t, and g_c in the observed period are taken as known, not estimated, values). Point forecasts and projection intervals for the age-standardised alcohol-attributable mortality fractions were obtained by age-standardising over each sample path separately.

- **Full projections by country and sex**

For the full projections by country and sex, including the projection of the period and cohort parameter, please see pages 41 - 95 of this working paper.
The fitted age-specific and fitted age-standardised AAMF values represent the fitted values in which the burned estimates for the youngest cohorts are replaced with the projected cohort values.
Regarding the age-specific AAMF plots, it should be noted that we compared the observed values for a five-year age group with the fitted value for a single year of age. For example, for the 20-24 age group, we compared the observed value for this age group with the fitted value for age 22, whereas the average age for the age group was 22.5. This approach led to small differences. It should also be noted when appraising the age-specific fit that for the older age groups in particular, the AAMF values are very much zoomed in.

Software

For our analysis, we used the R software version 3.6.2 in R Studio 1.2.5033.

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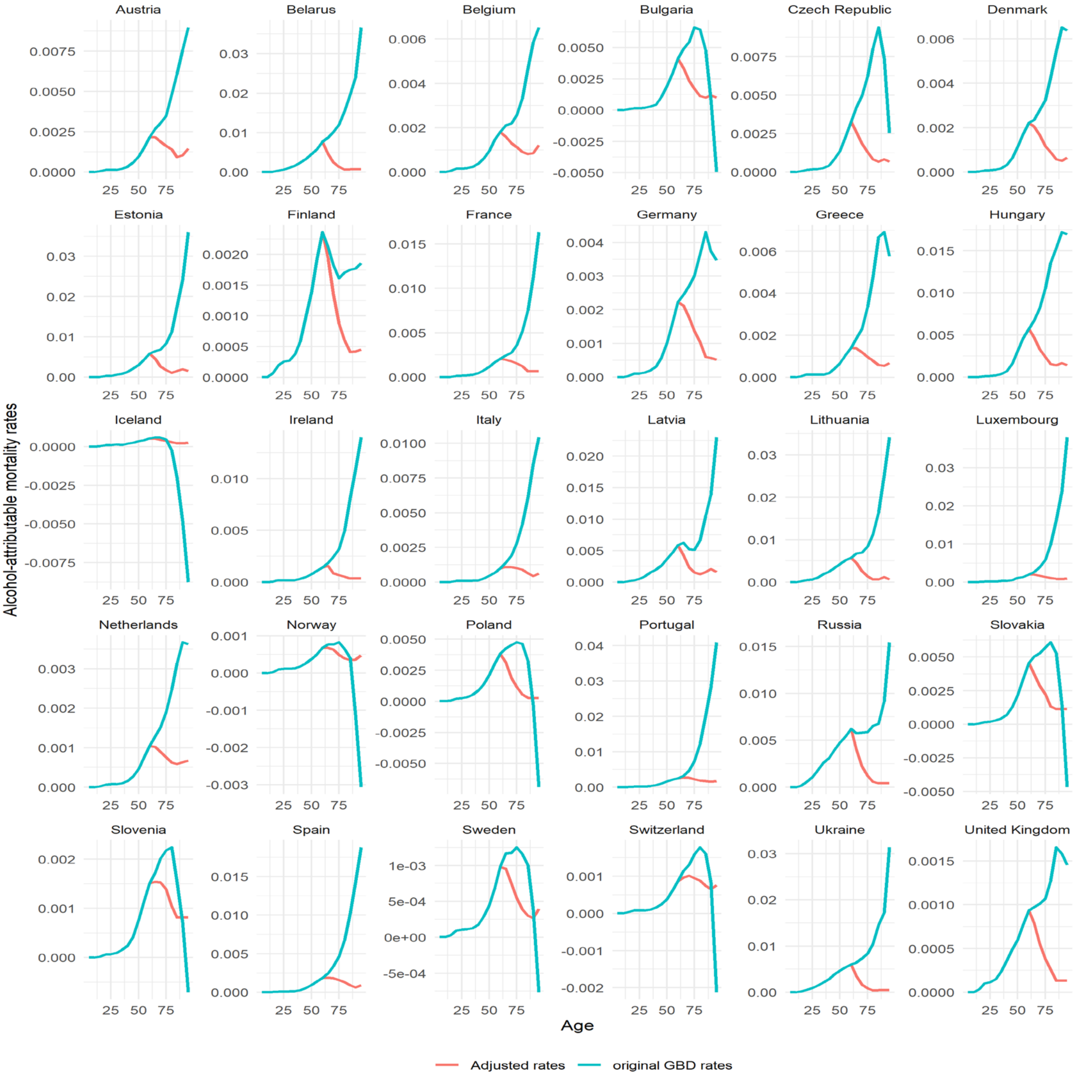
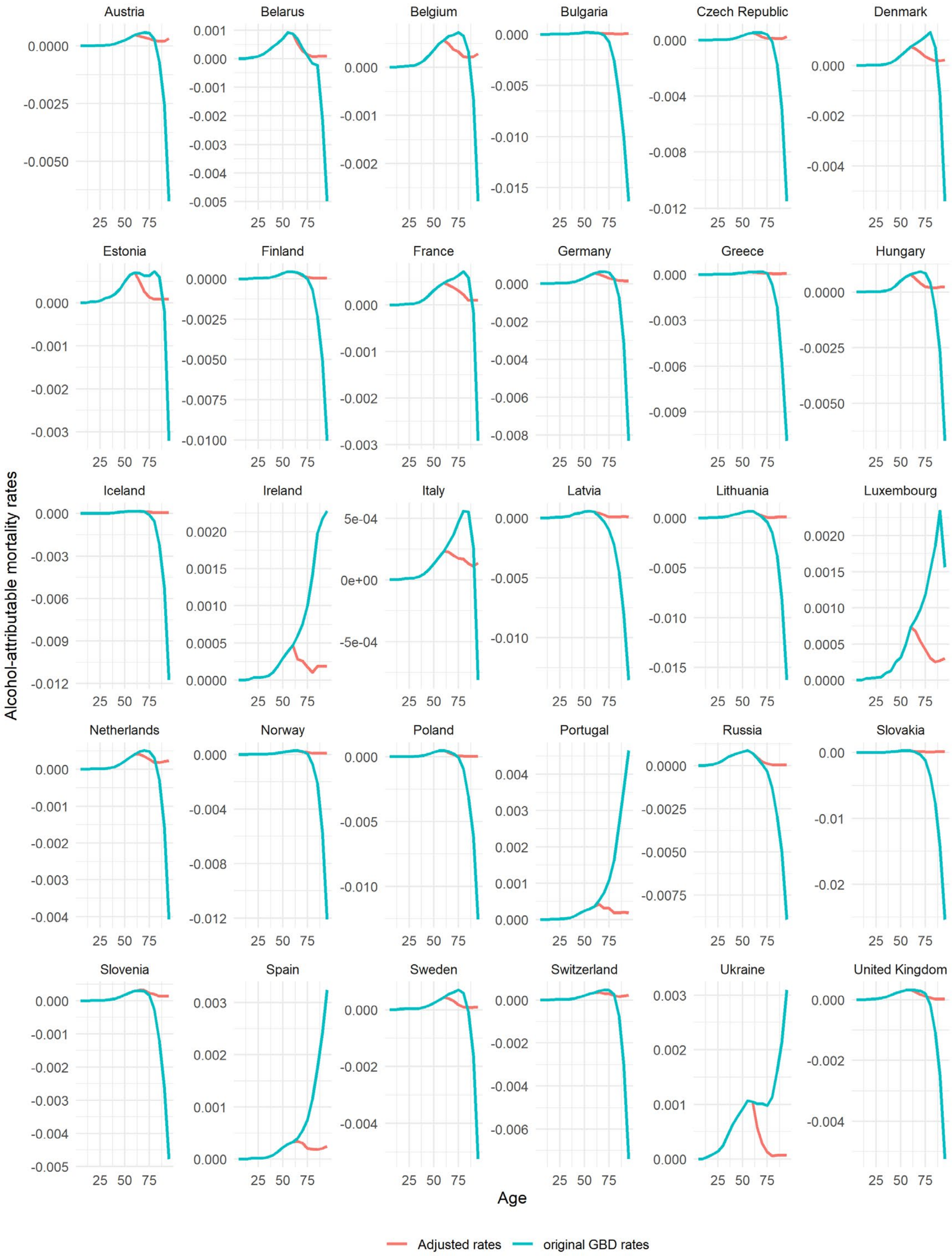
Appendix S1 - Comparison of our adjusted age-specific and age-standardised alcohol-attributable mortality rates with the respective original GBD rates

Appendix Figure S1 – Comparison of the age-specific alcohol-attributable mortality rates in 2014 (or latest available year), original GBD estimates versus our adjusted estimates, 30 European countries, by sex

a) Males

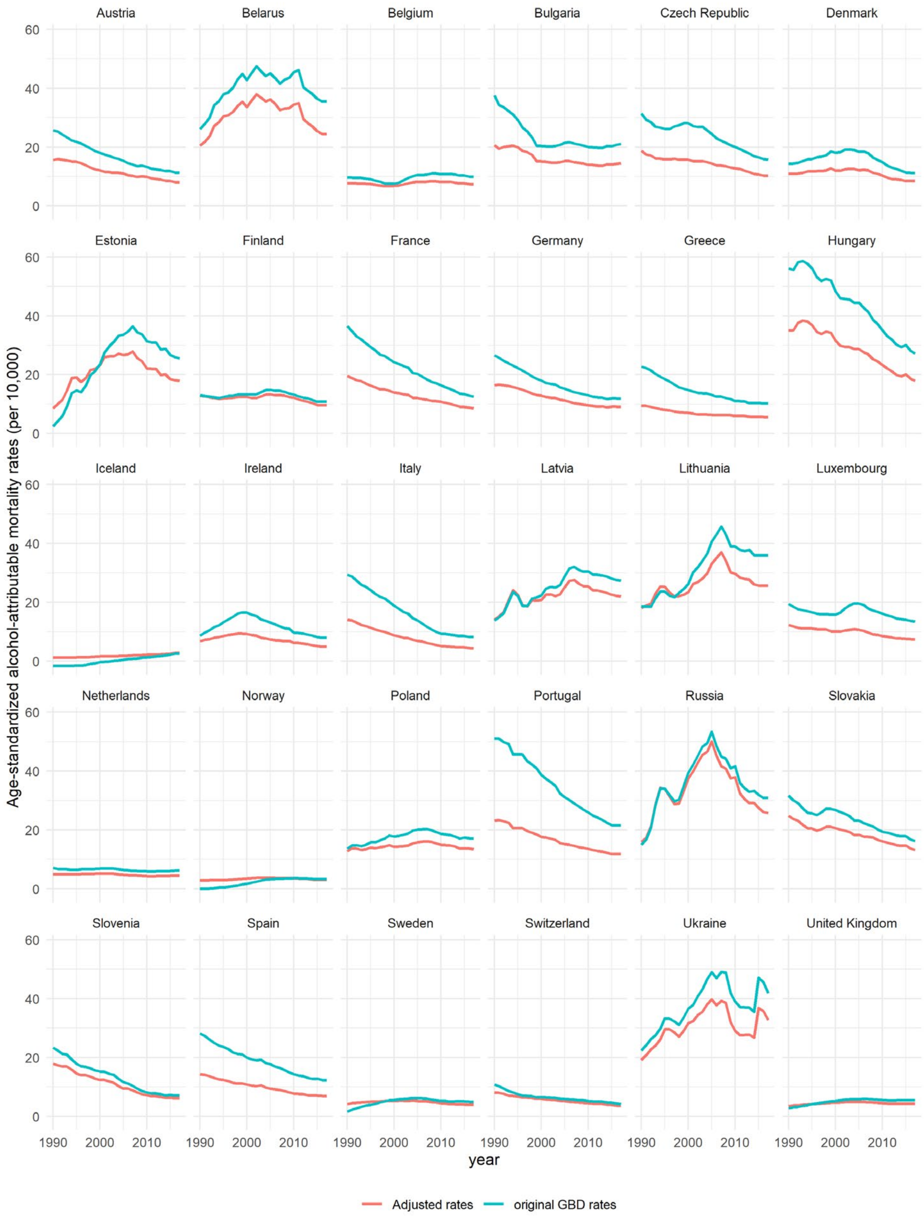


b) Females

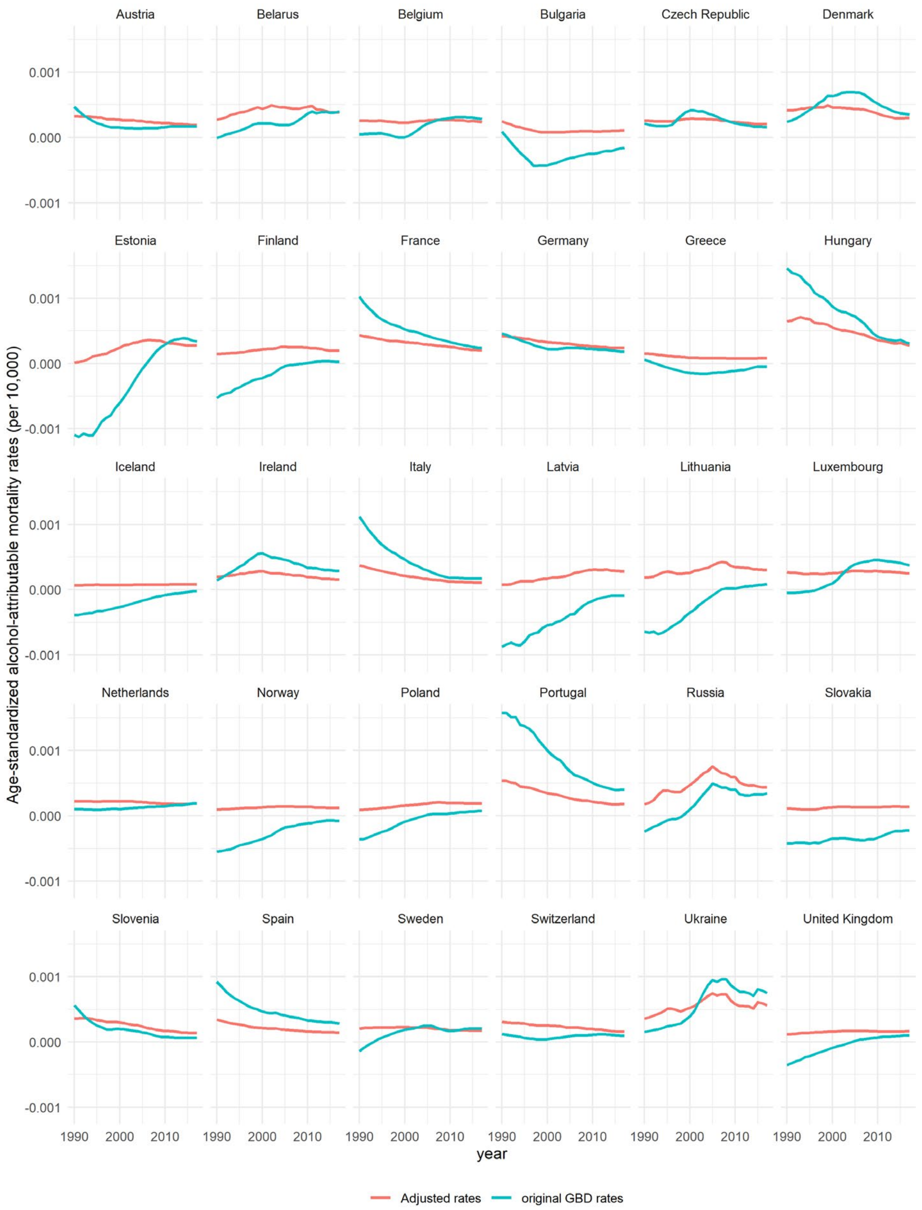

Austria
Belarus
Belgium
Bulgaria
Czech Republic
Denmark
Estonia
Finland
France
Germany
Greece
Hungary
Iceland
Ireland
Italy
Latvia
Lithuania
Luxembourg
Netherlands
Norway
Poland
Portugal
Russia
Slovakia
Slovenia
Spain
Sweden
Switzerland
Ukraine
United Kingdom
Alcohol-attributable mortality rates
Age
Adjusted rates
original GBD rates

Appendix Figure S2 – Comparison of the age-standardised* alcohol-attributable mortality rates (20-99), 1990-2014, either based on the original GBD estimates or based on our adjusted estimates, 30 European countries, by sex

a) Males



b) Females

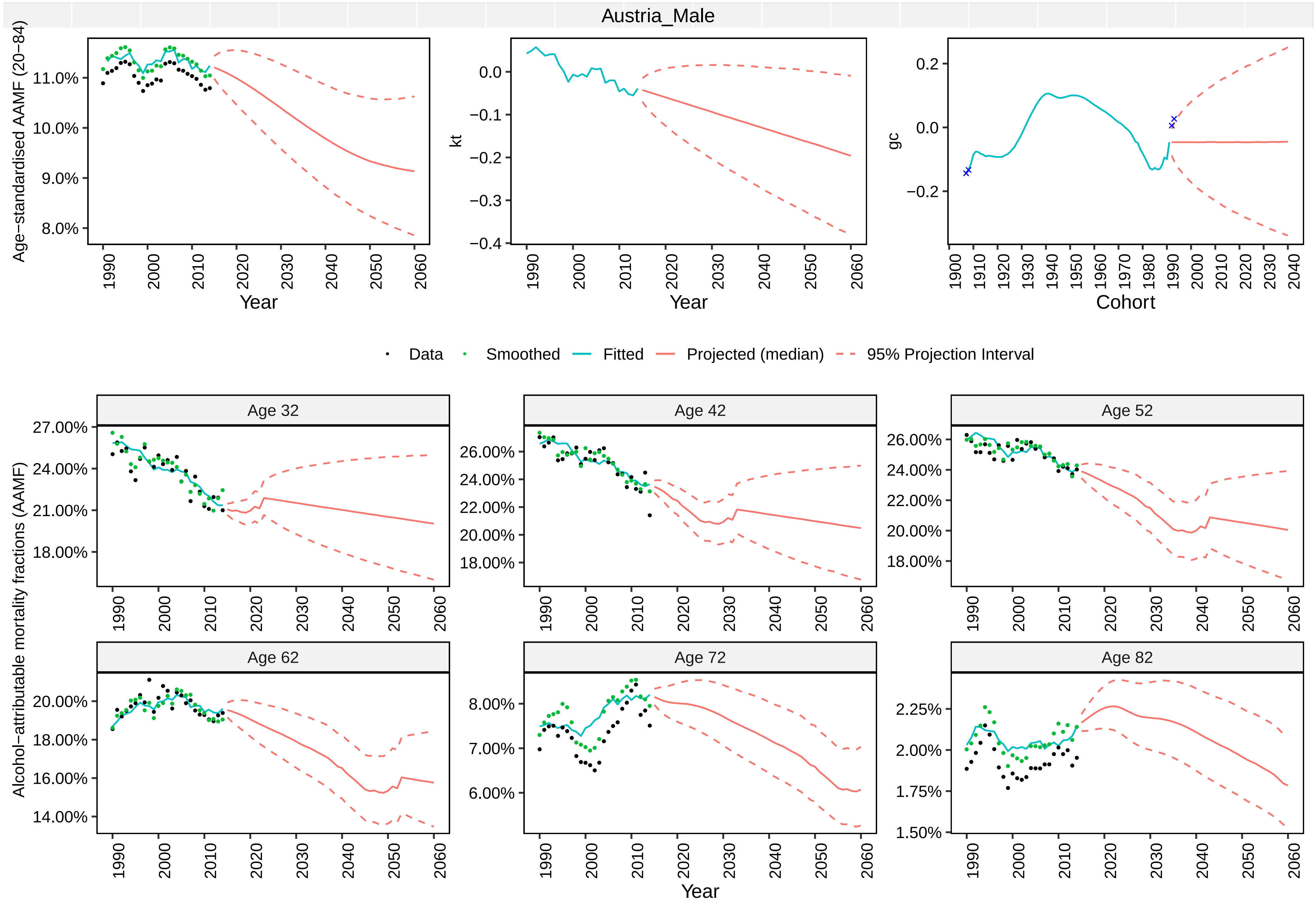


* Direct age standardisation was conducted using as the standard population the country and sex specific population distribution in 2010 (based on HMD data).

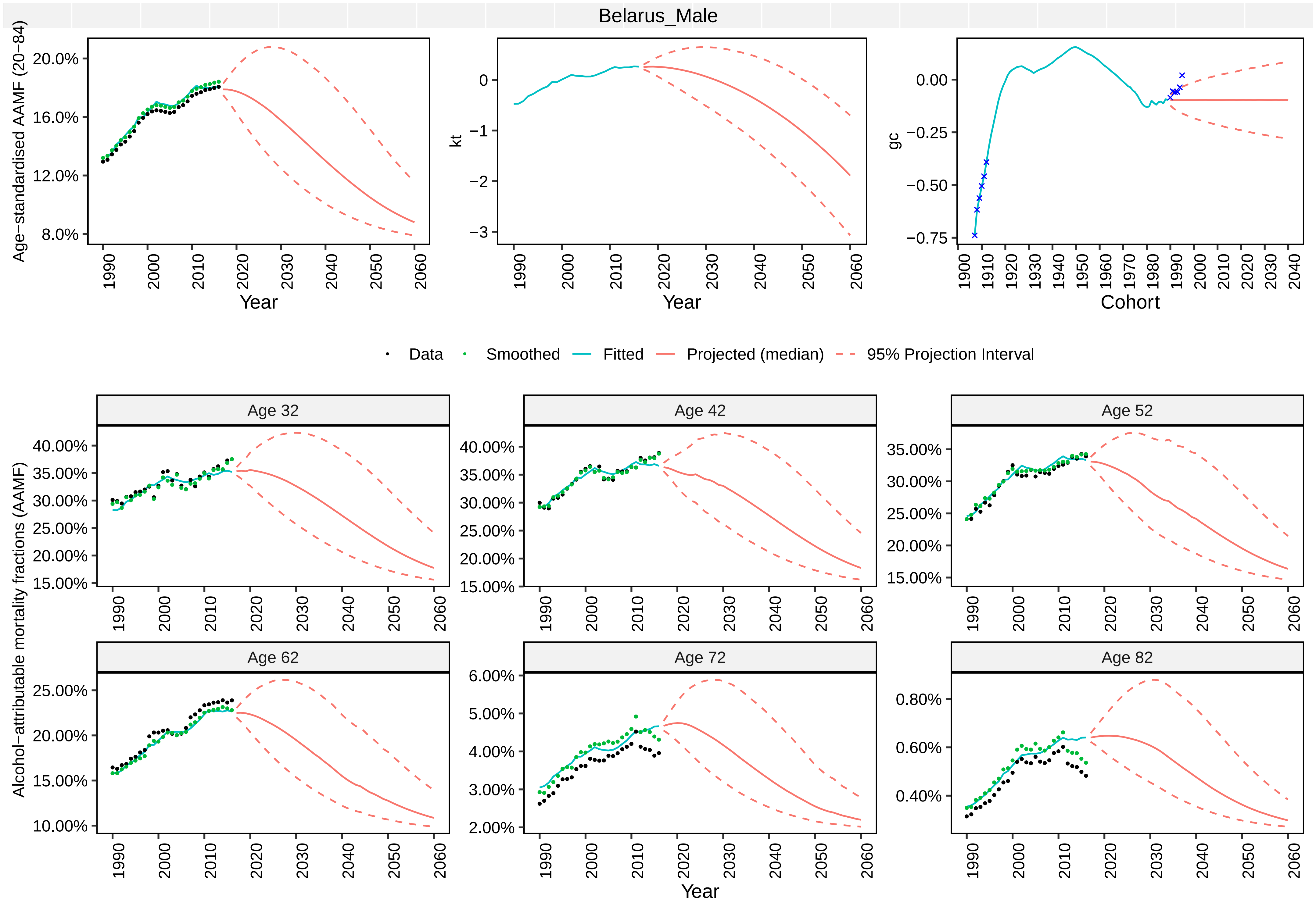
Detailed projections by country and sex

a) Past and future age-standardised (20-84) and age-specific (selected ages) alcohol-attributable mortality fractions, 1990-2060, by country, for men (pages 42 – 68).

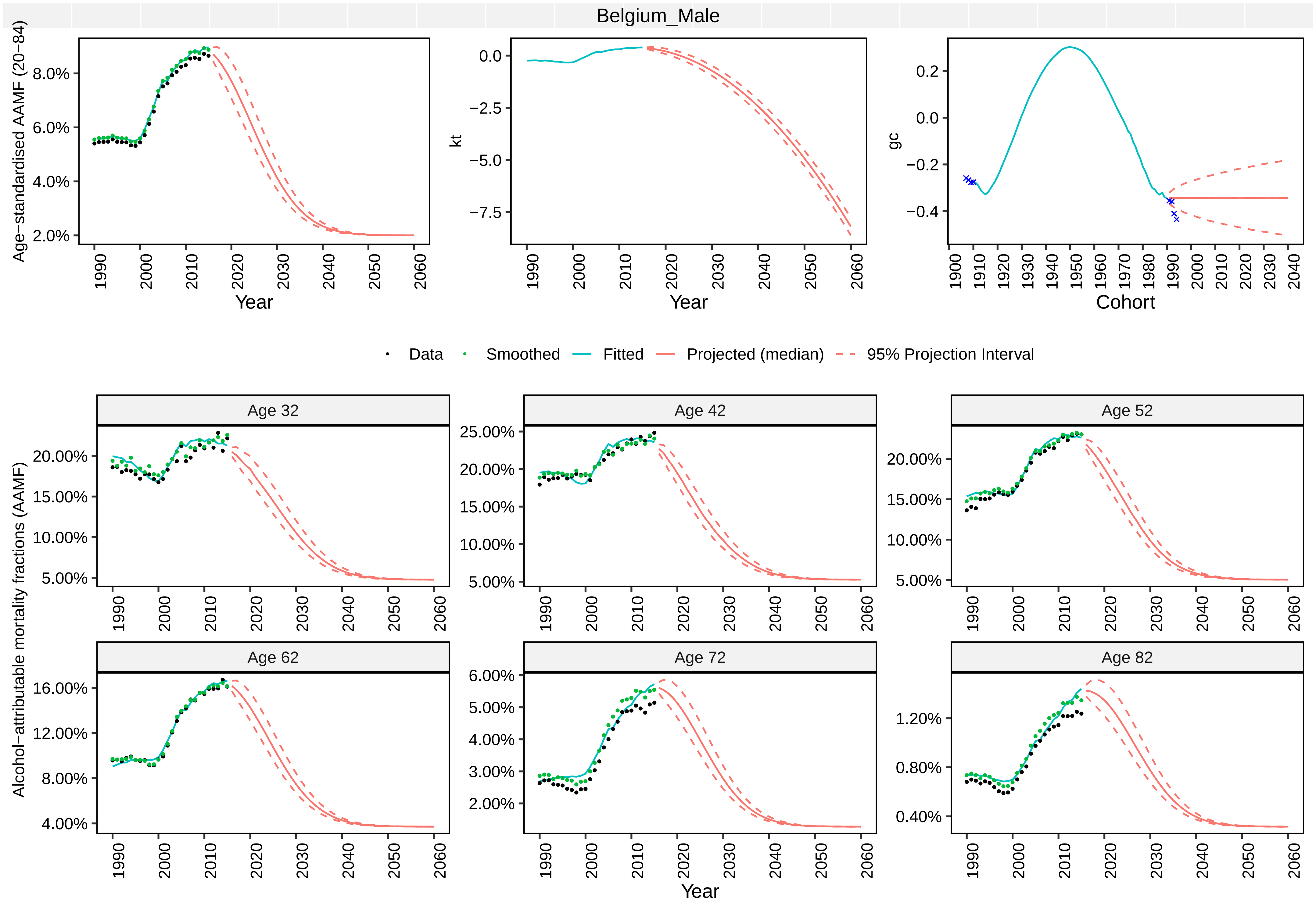
b) Past and future age-standardised (20-84) and age-specific (selected ages) alcohol-attributable mortality fractions, 1990-2060, by country, for women (pages 69 – 95).



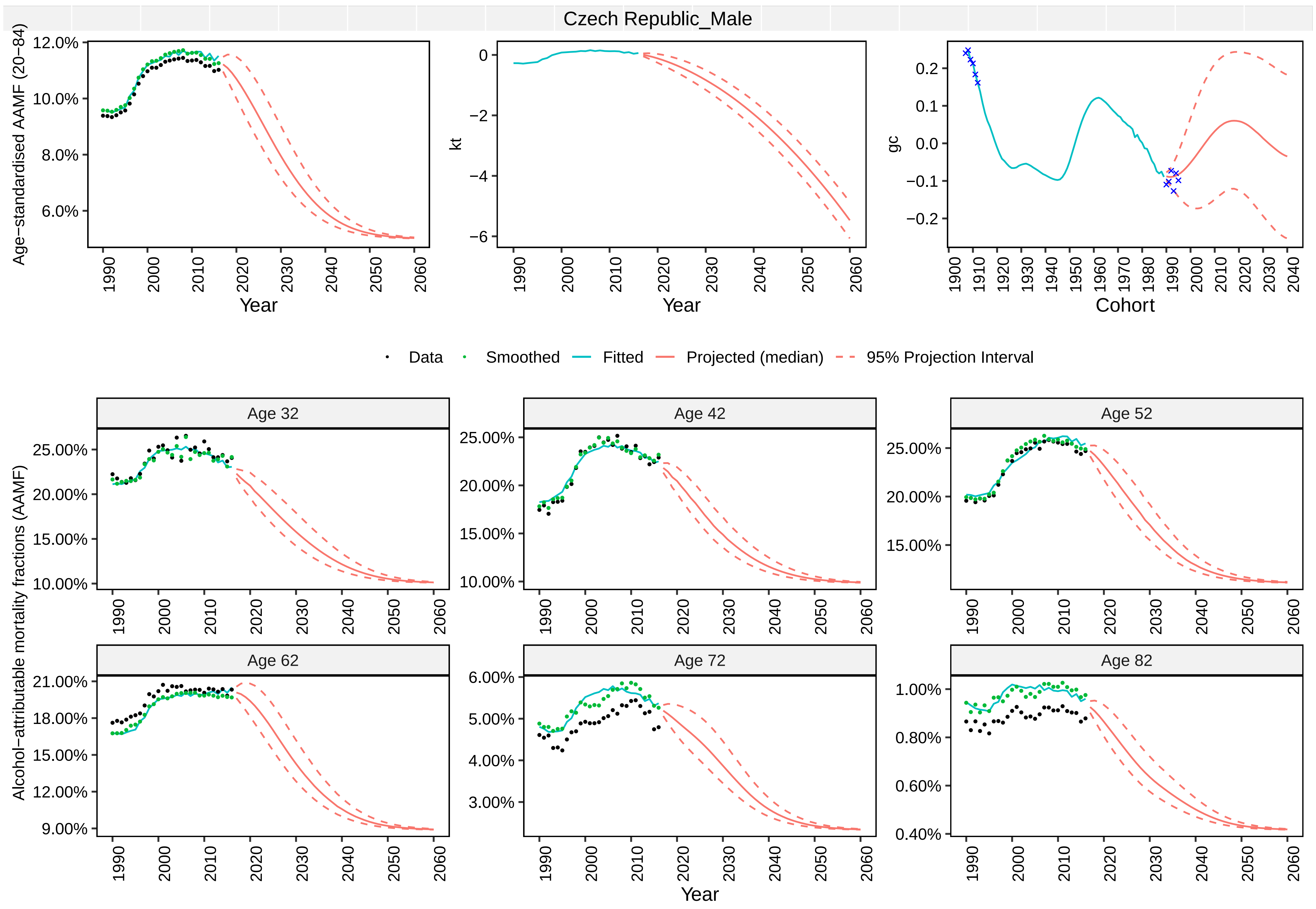
Austria_Male
Age−standardised AAMF (20−84)
11.0%
10.0%
9.0%
8.0%
Year
kt
0.0
−0.1
−0.2
−0.3
−0.4
gc
0.2
0.0
−0.2
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



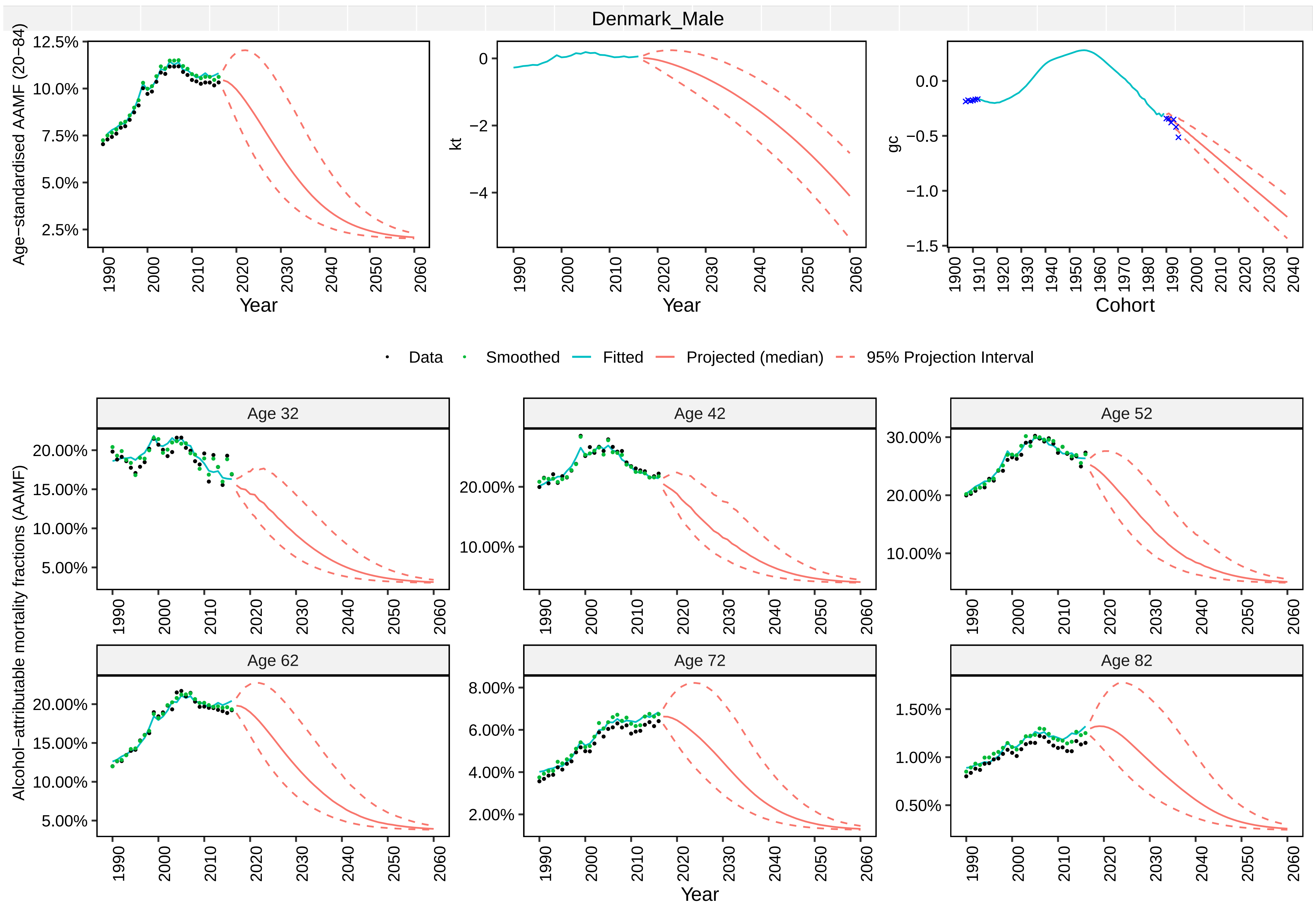
Belarus_Male
Age−standardised AAMF (20−84)
20.0%
16.0%
12.0%
8.0%
Year
kt
0
−1
−2
−3
gc
0.00
−0.25
−0.50
−0.75
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Year



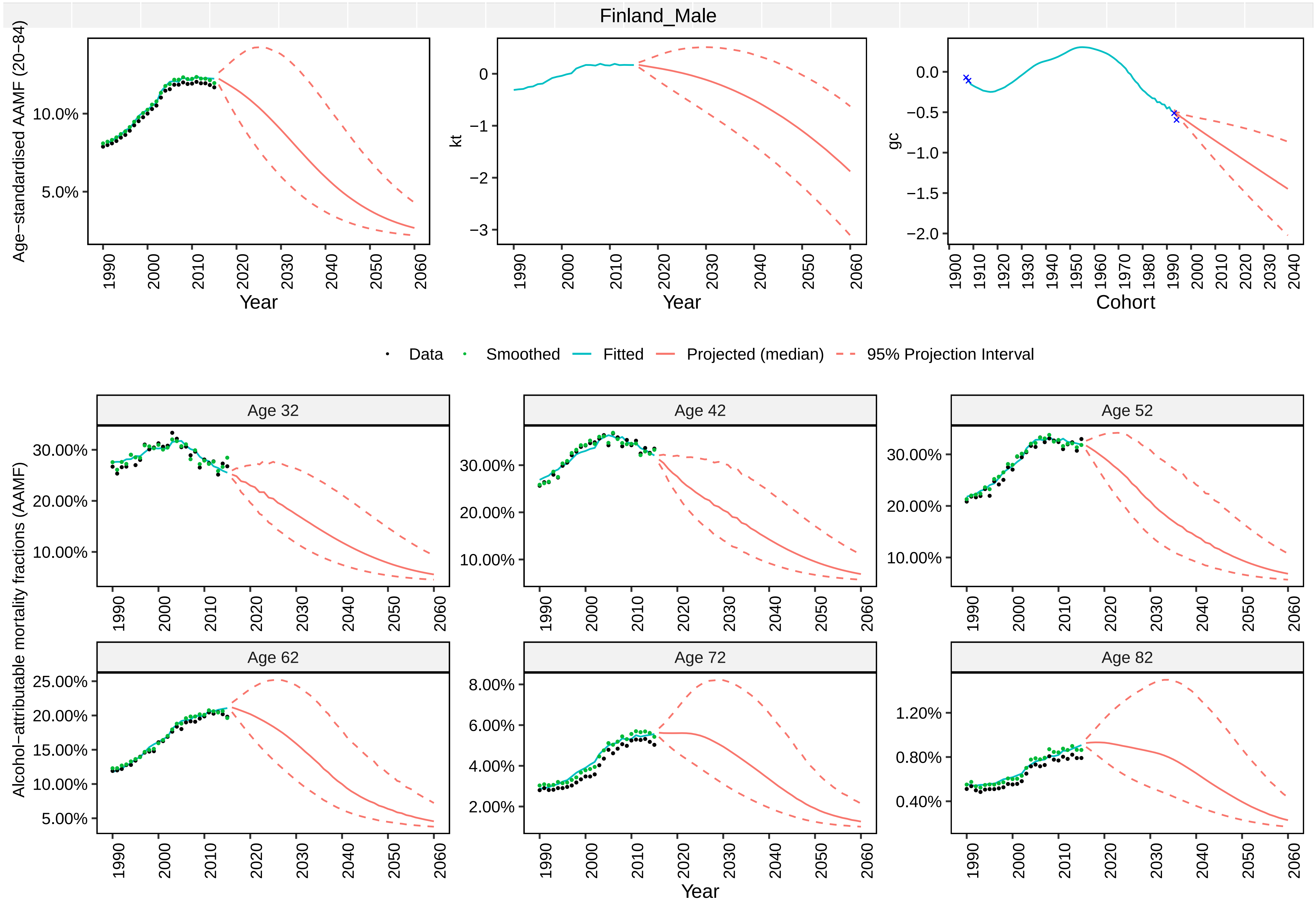
Belgium_Male
Age−standardised AAMF (20−84)
8.0%
6.0%
4.0%
2.0%
Year
kt
0.0
−2.5
−5.0
−7.5
Year
gc
0.2
0.0
−0.2
−0.4
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
20.00%
15.00%
10.00%
5.00%
25.00%
16.00%
12.00%
8.00%
4.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.20%
0.80%
0.40%
1990
2000
2010
2020
2030
2040
2050
2060
Year

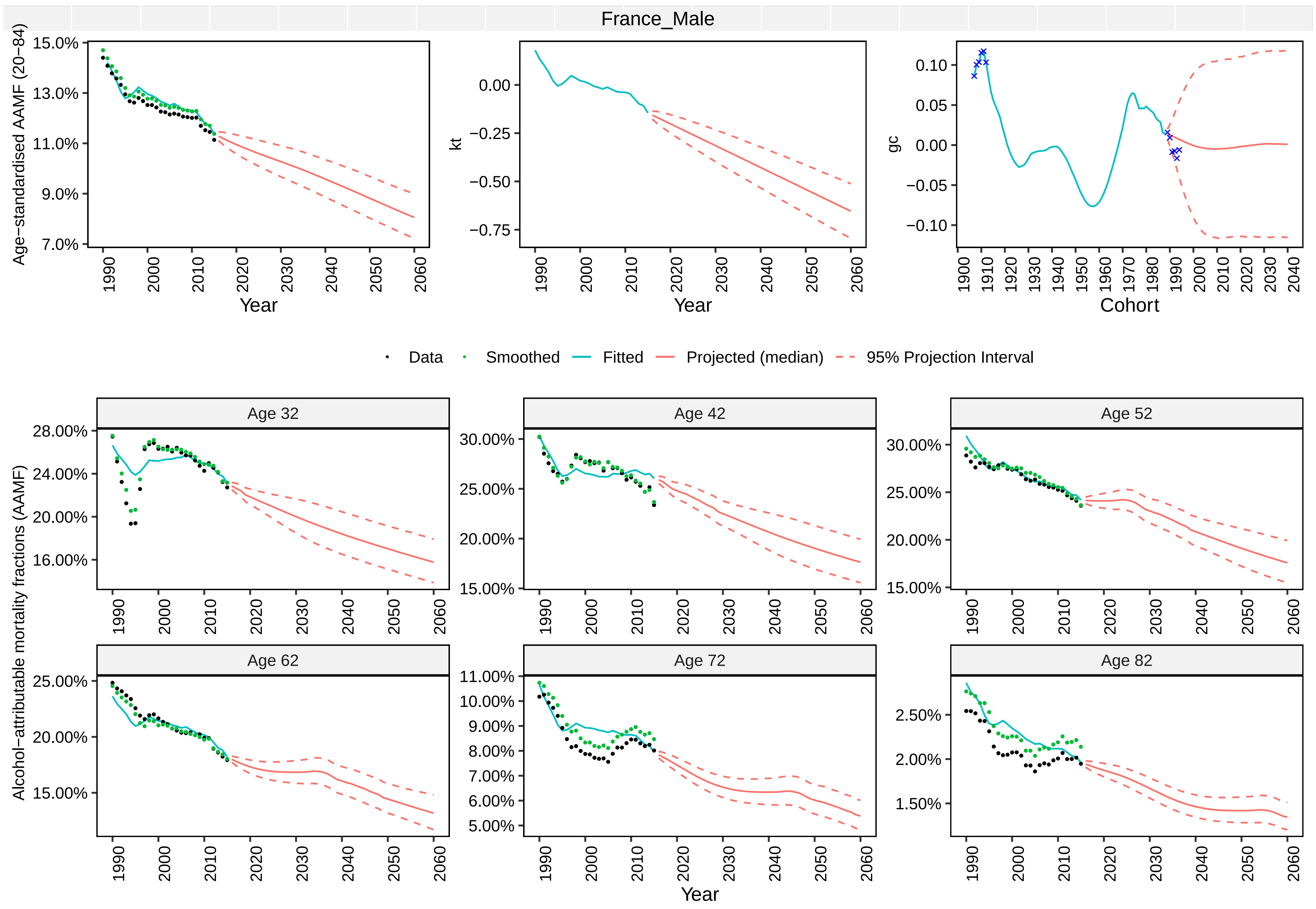


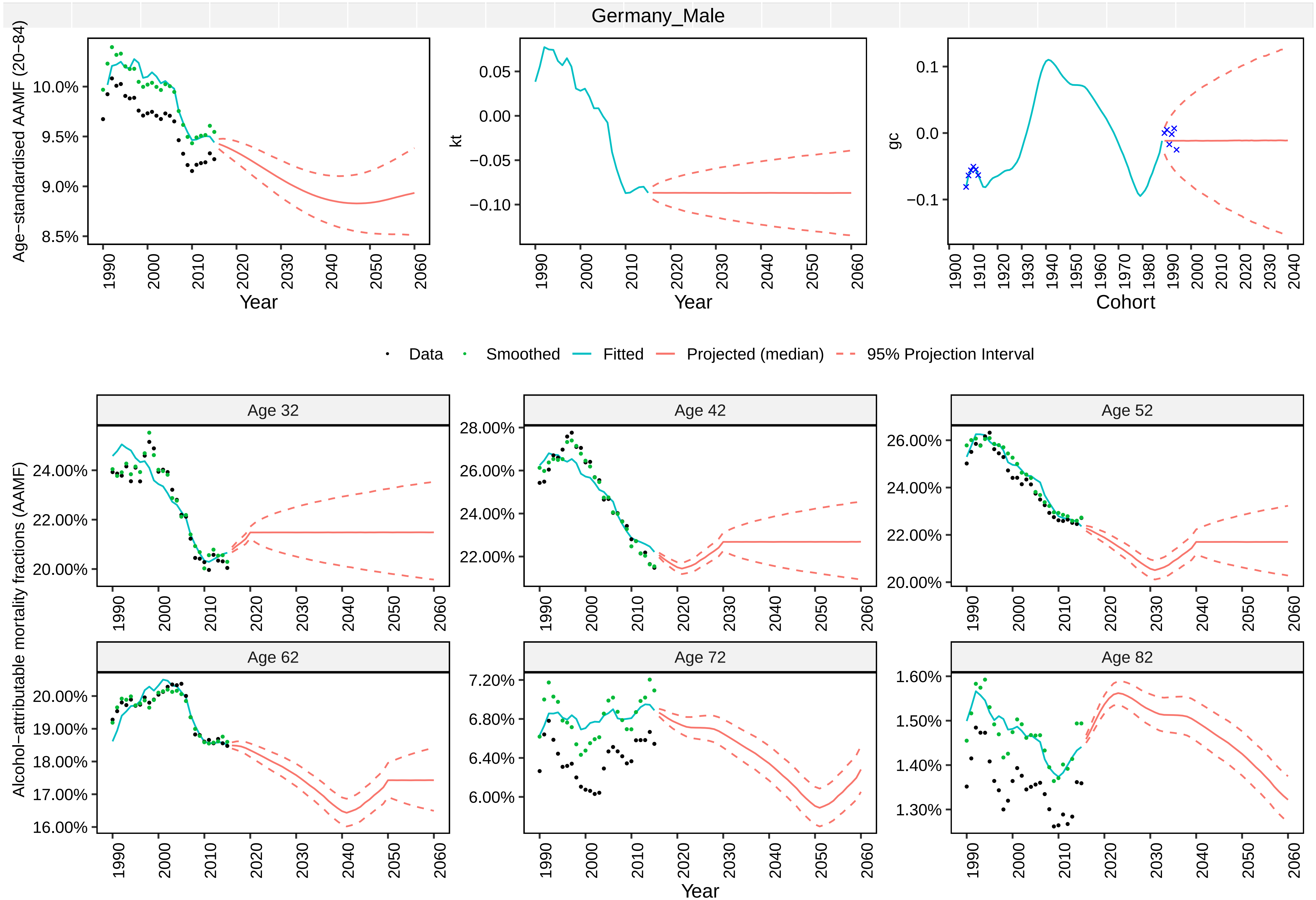
Czech Republic_Male
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)



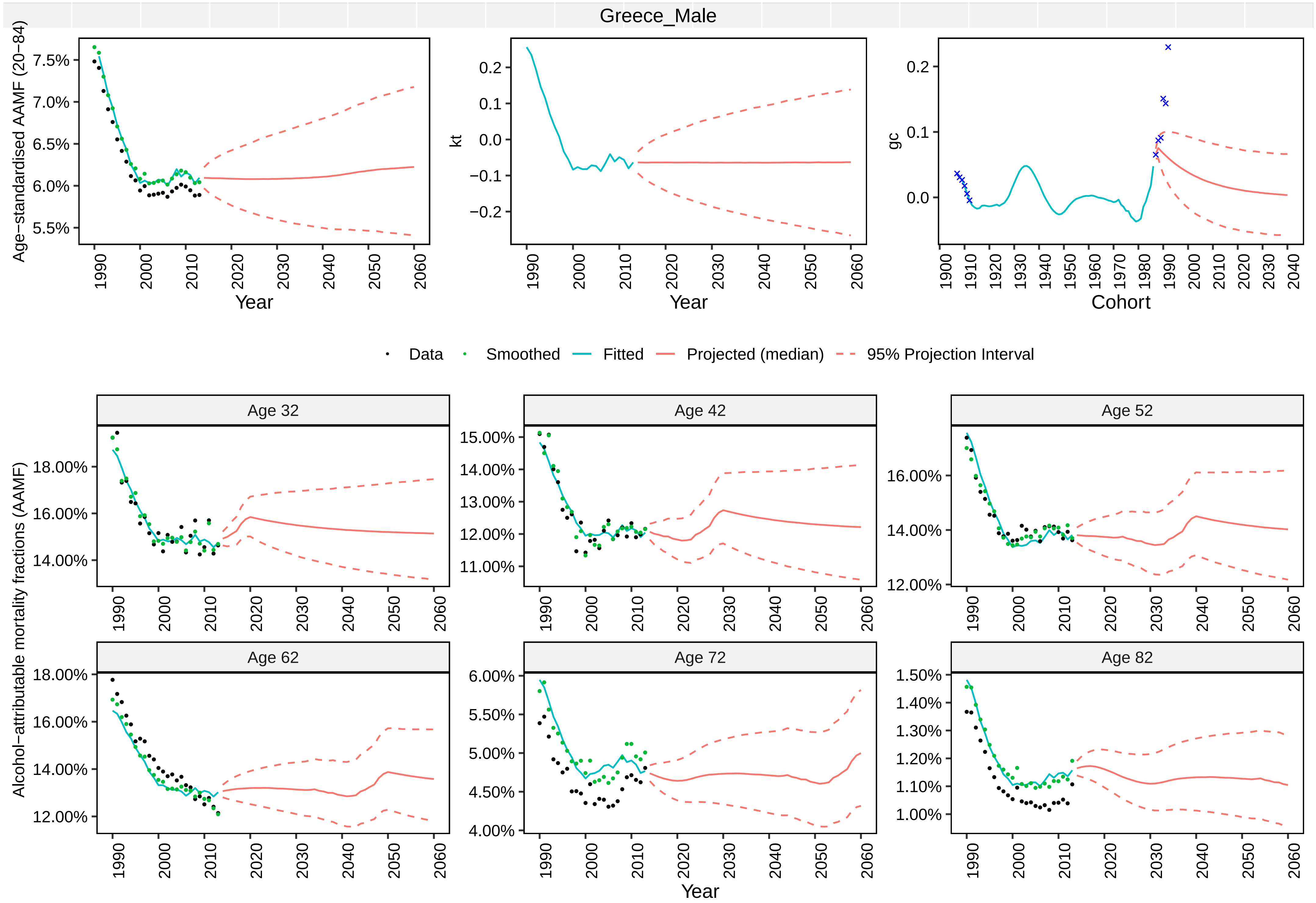
Denmark_Male
Age−standardised AAMF (20−84)
12.5%
10.0%
7.5%
5.0%
2.5%
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

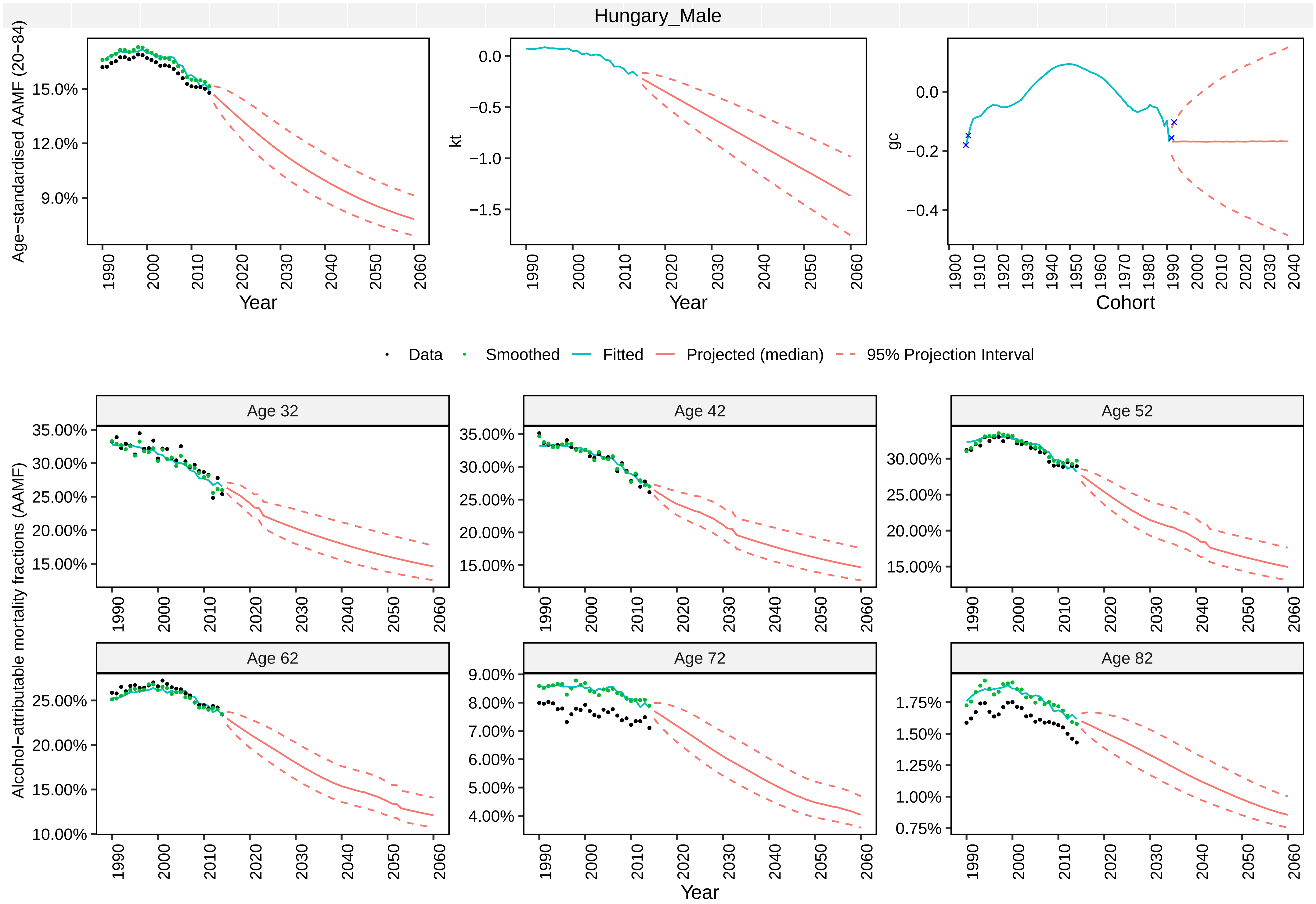

Finland_Male
Age−standardised AAMF (20−84)
10.0%
5.0%
Year
kt
0
−1
−2
−3
gc
0.0
−0.5
−1.0
−1.5
−2.0
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
30.00%
20.00%
10.00%
25.00%
15.00%
5.00%
8.00%
6.00%
4.00%
2.00%
1.20%
0.80%
0.40%
1990
2000
2010
2020
2030
2040
2050
2060
1900
1910
1920
1930
1940
1950
1960
1970
1980
Year

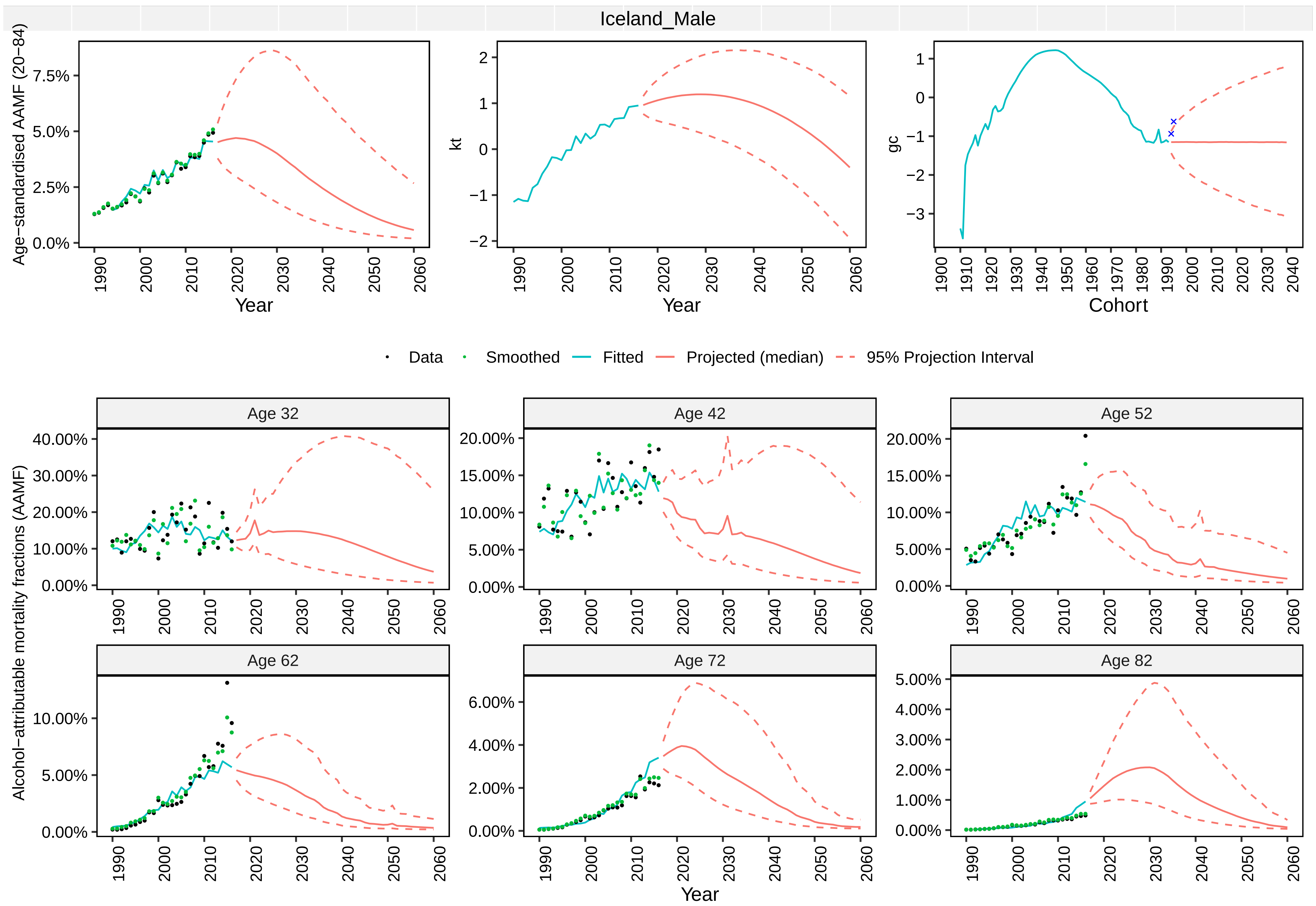

France_Male
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)



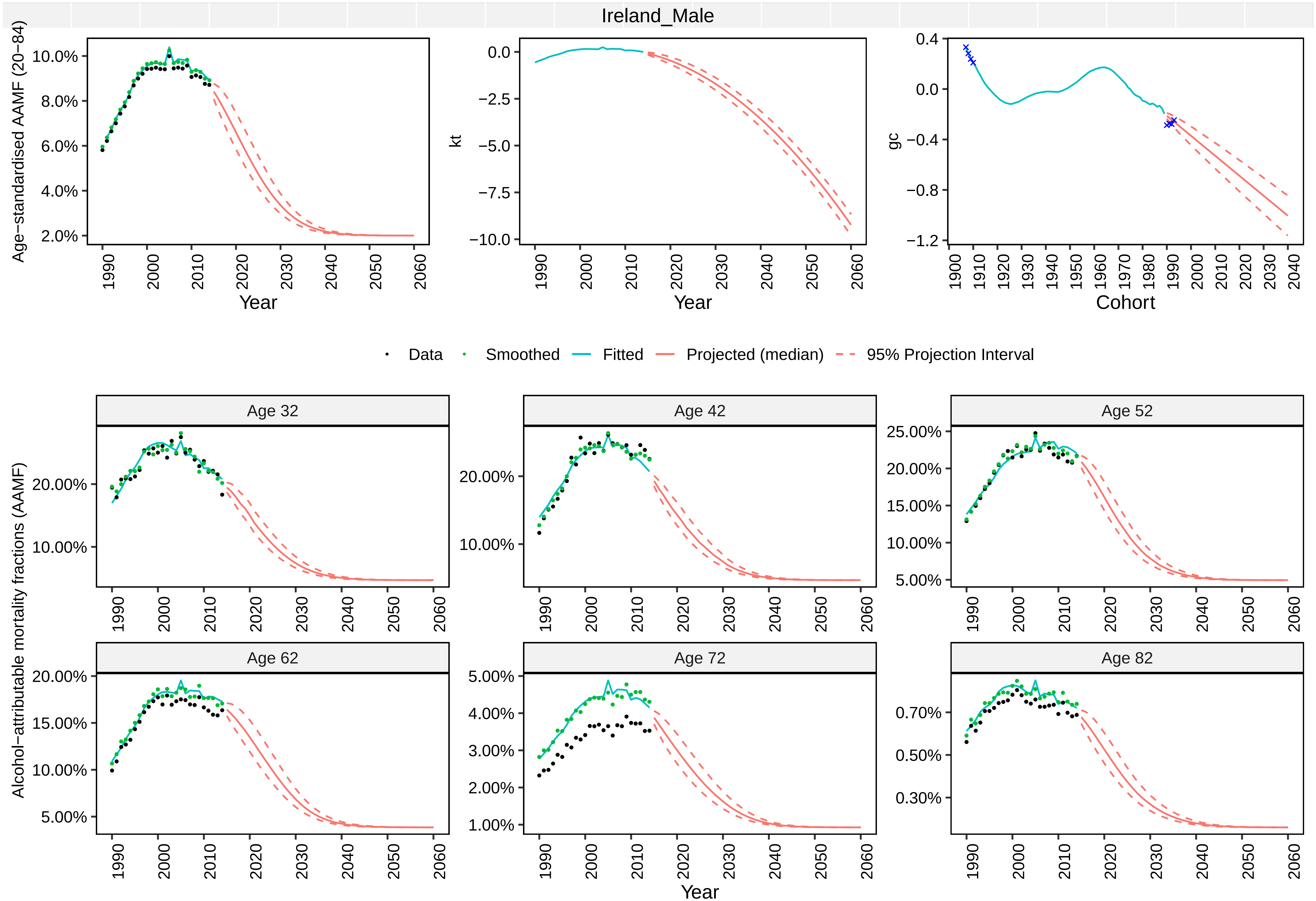
Germany_Male
Age−standardised AAMF (20−84)
kt
gc
Year
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)


Greece_Male
Age−standardised AAMF (20−84)
7.5%
7.0%
6.5%
6.0%
5.5%
Year
kt
0.2
0.1
0.0
−0.1
−0.2
Year
gc
0.2
0.1
0.0
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

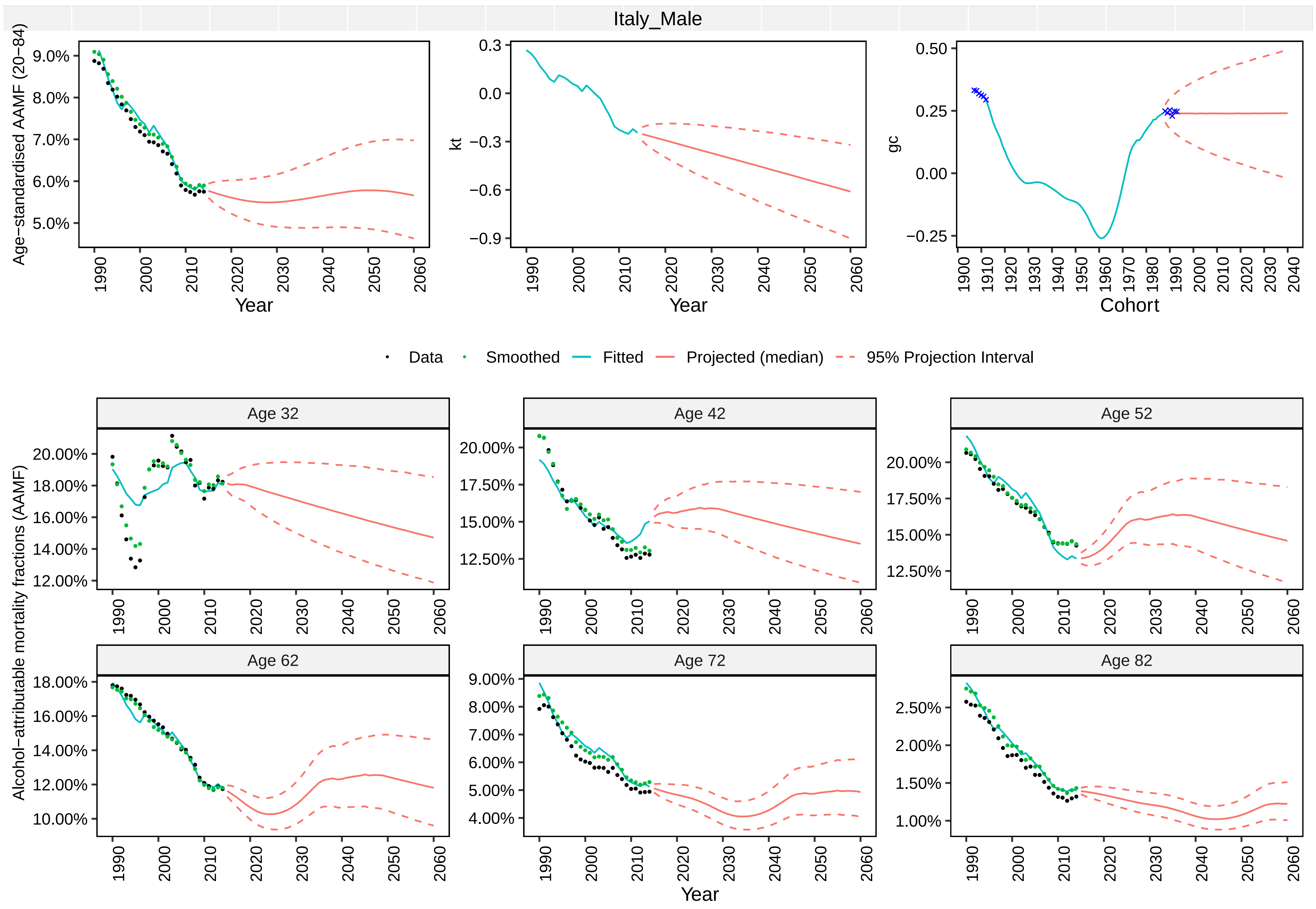

Hungary_Male
Age−standardised AAMF (20−84)
15.0%
12.0%
9.0%
Year
kt
0.0
−0.5
−1.0
−1.5
gc
−0.2
−0.4
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
1990
2000
2010
2020
2030
2040
2050
2060



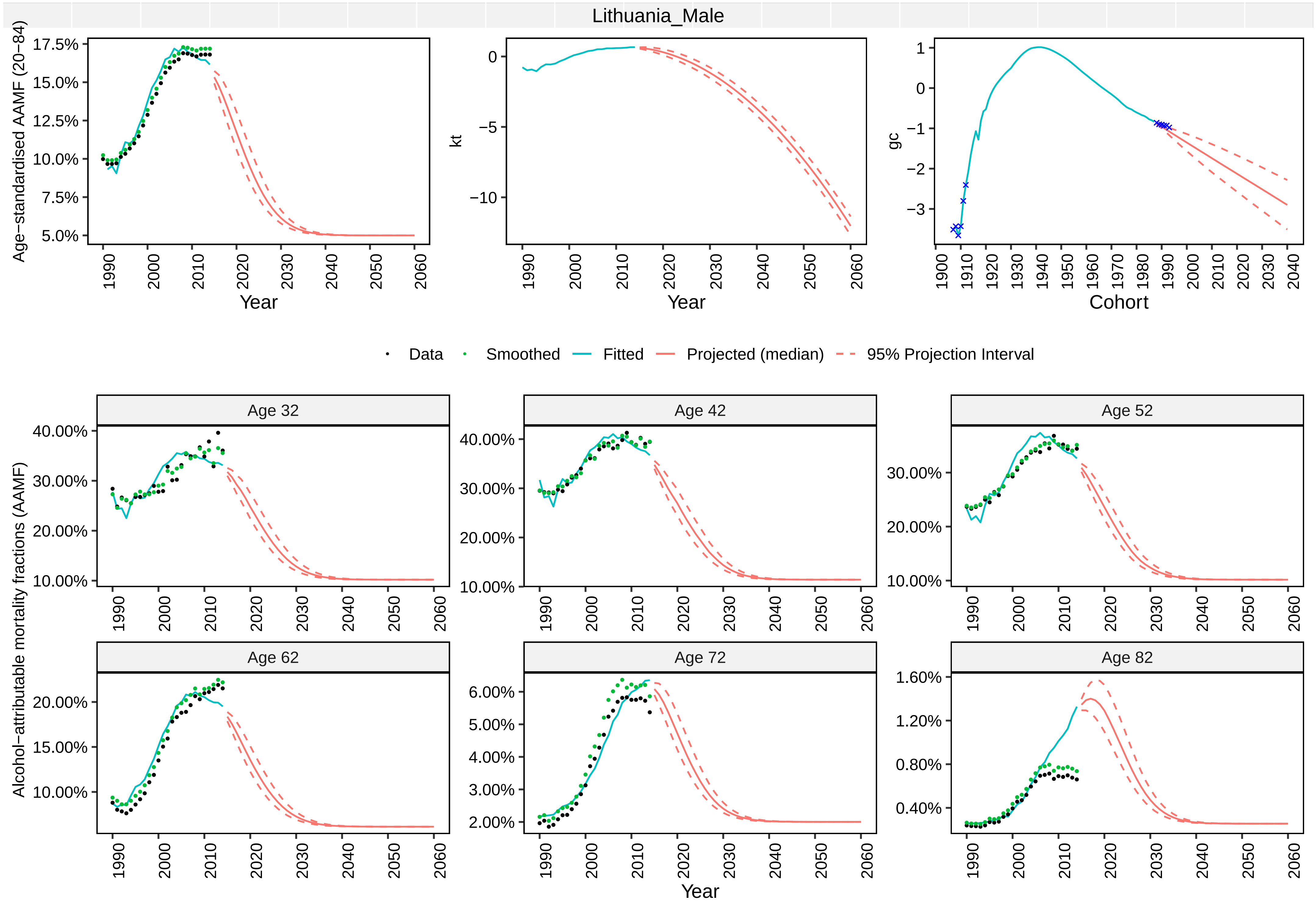
Iceland_Male
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



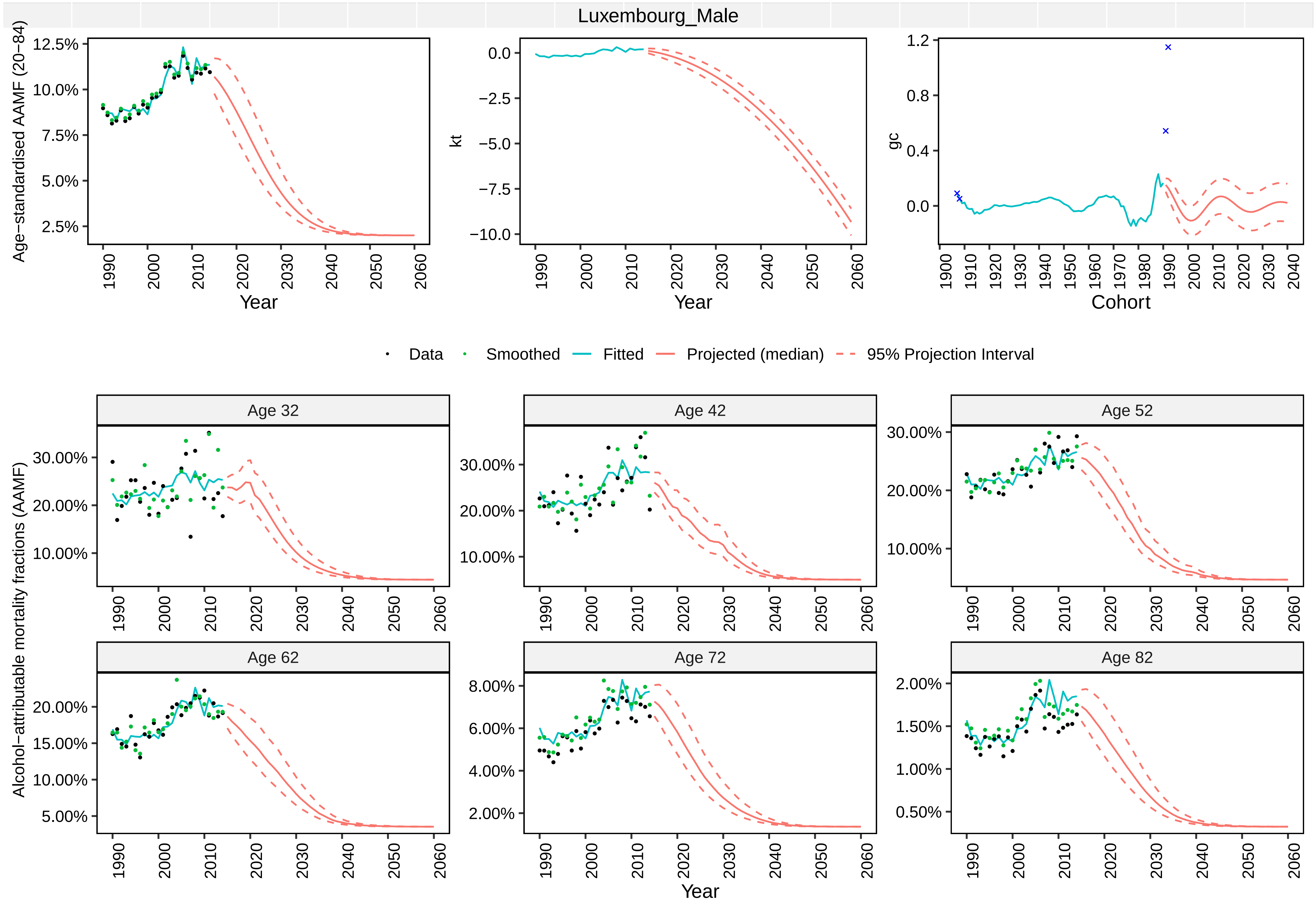
Ireland_Male
Age−standardised AAMF (20−84)
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



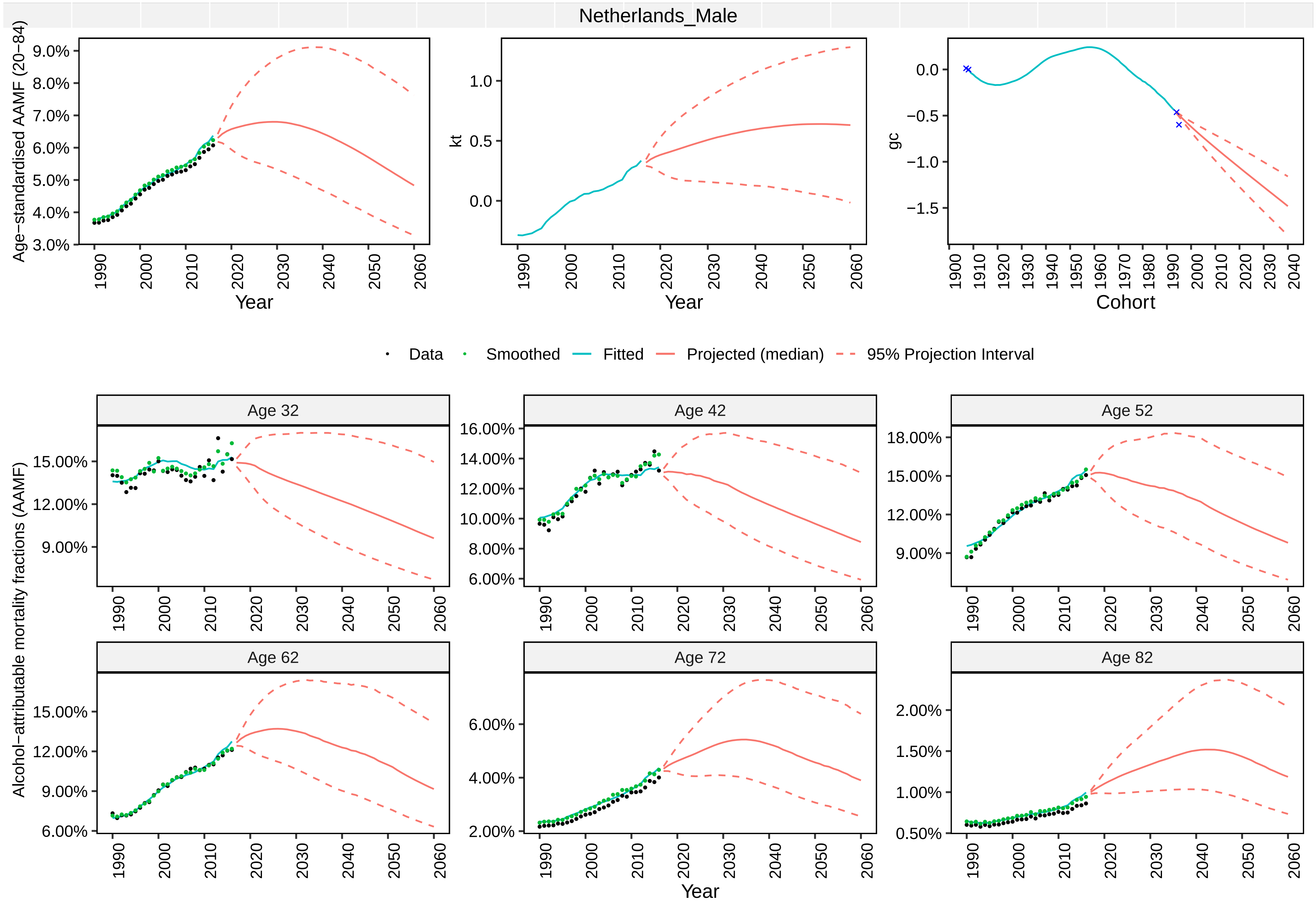
Italy_Male
Age−standardised AAMF (20−84)
kt
gc
Year
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)

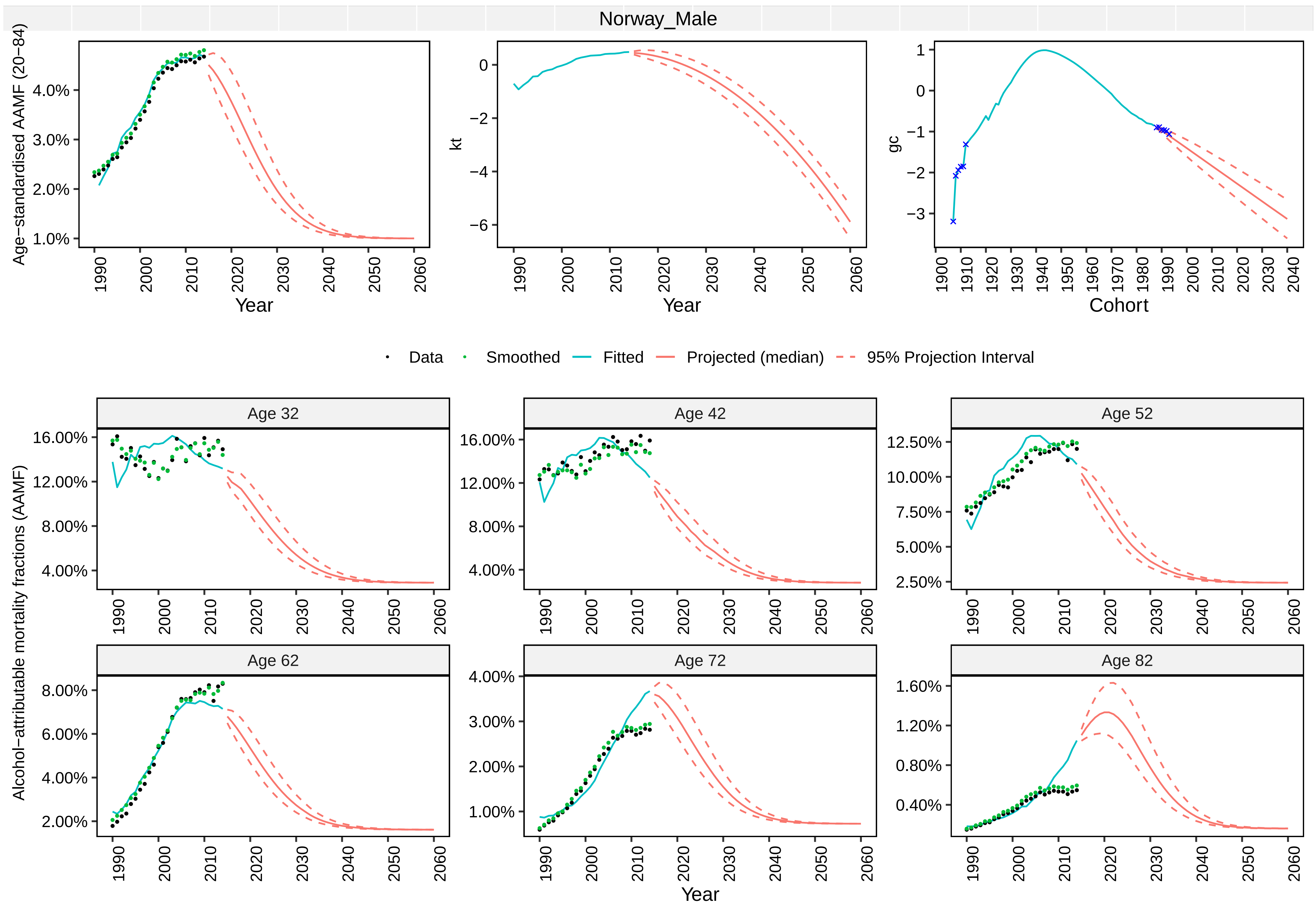


Lithuania_Male
Age−standardised AAMF (20−84)
17.5%
15.0%
12.5%
10.0%
7.5%
5.0%
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)

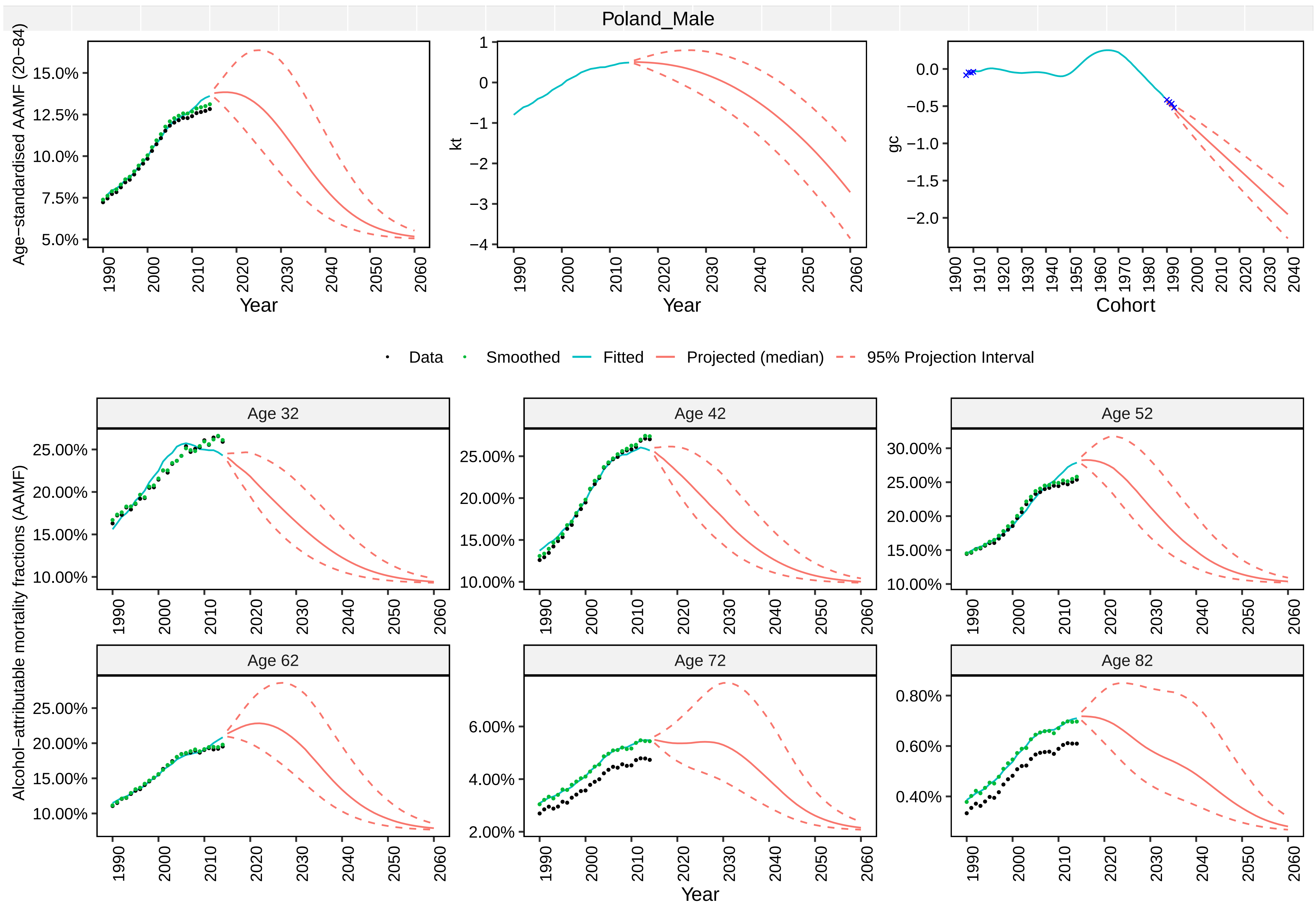


Luxembourg_Male
Age−standardised AAMF (20−84)
12.5%
10.0%
7.5%
5.0%
2.5%
Year
kt
0.0
−2.5
−5.0
−7.5
−10.0
gc
1.2
0.8
0.4
0.0
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
30.00%
20.00%
10.00%
15.00%
5.00%
8.00%
6.00%
4.00%
2.00%
1.50%
1.00%
0.50%
1990
2000
2010
2020
2030
2040
2050
2060
Year

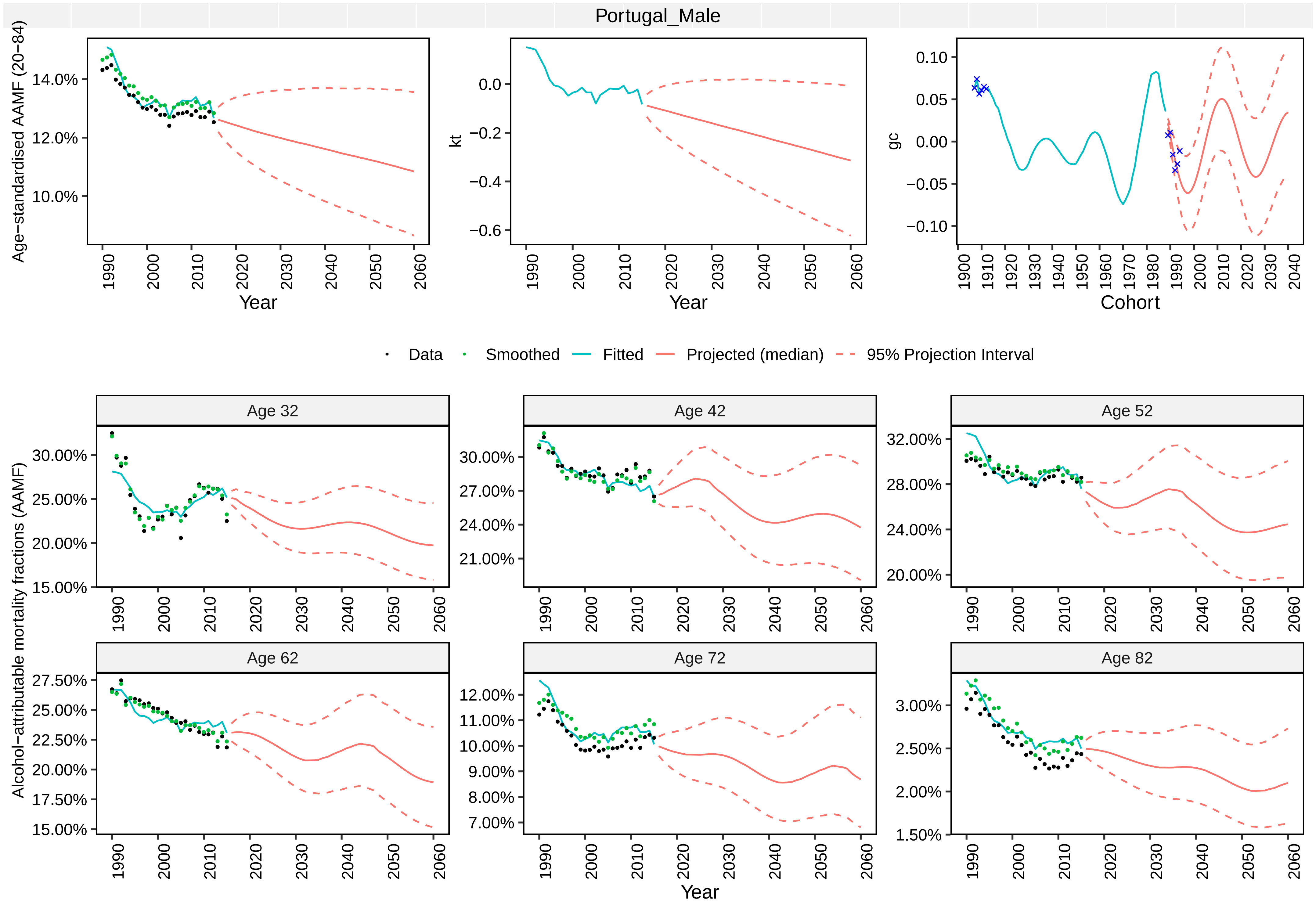

Netherlands_Male
Age−standardised AAMF (20−84)
kt
gc
Year
Year
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



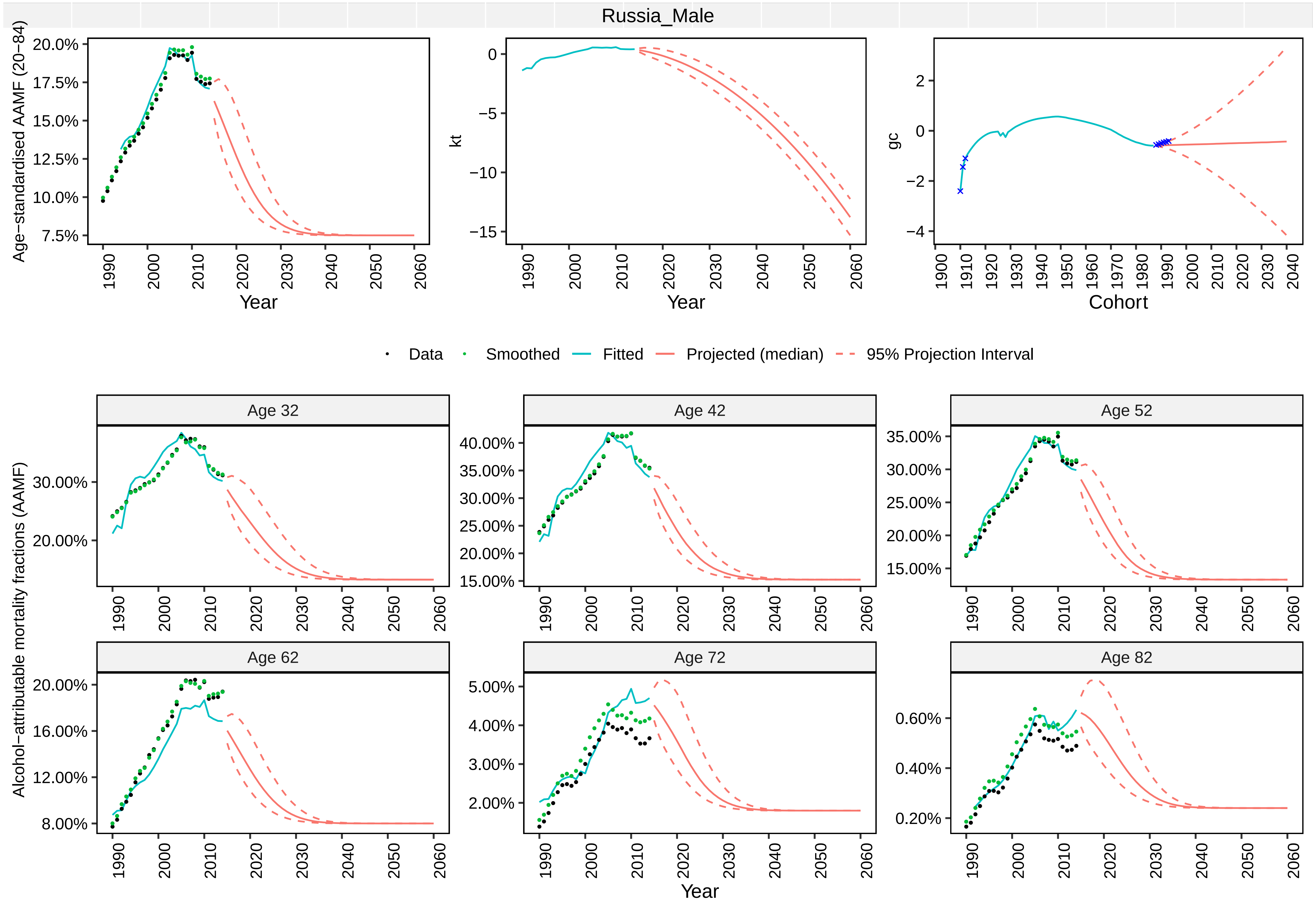
Norway_Male
Age−standardised AAMF (20−84)
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

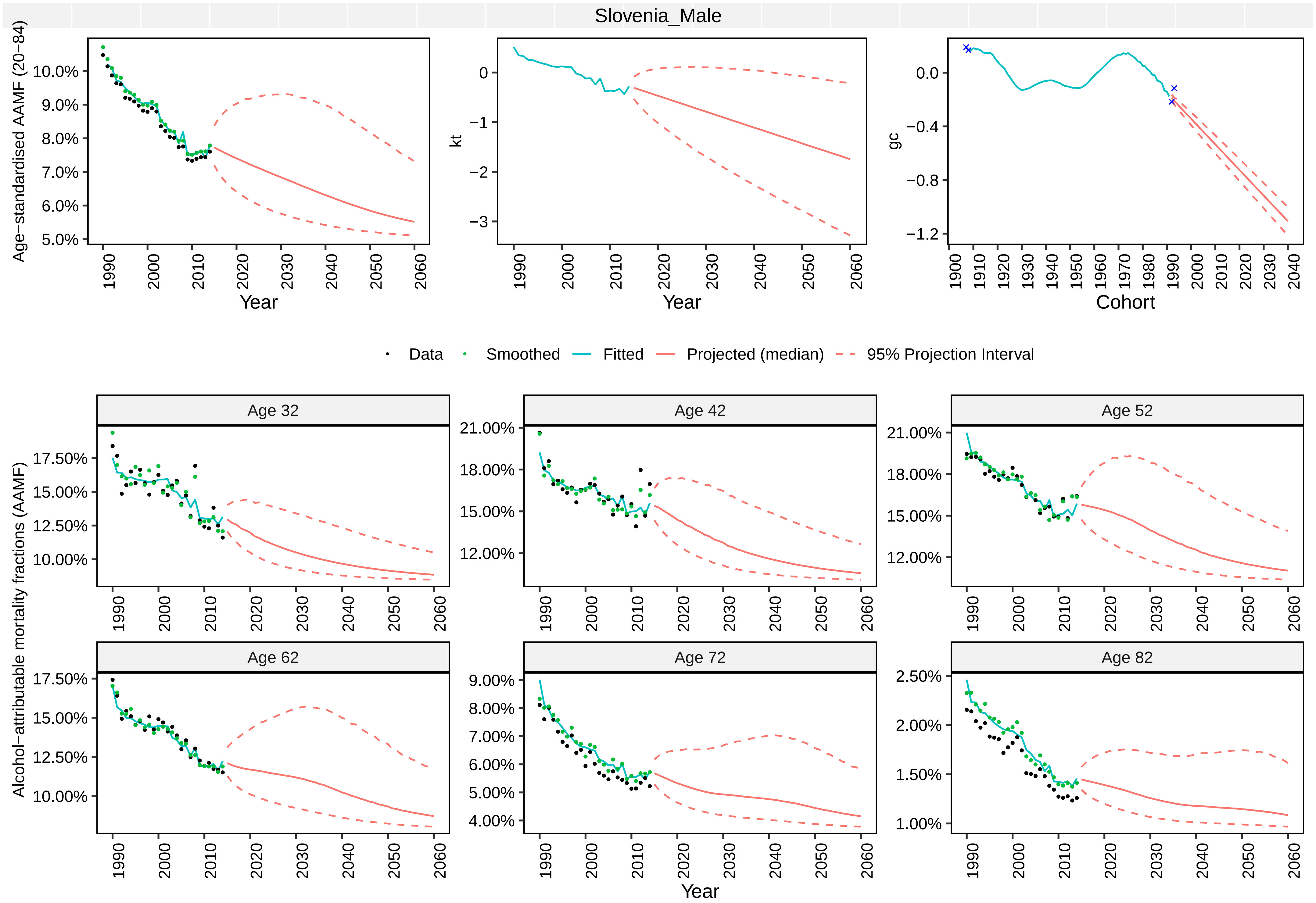


Poland_Male
Age−standardised AAMF (20−84)
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

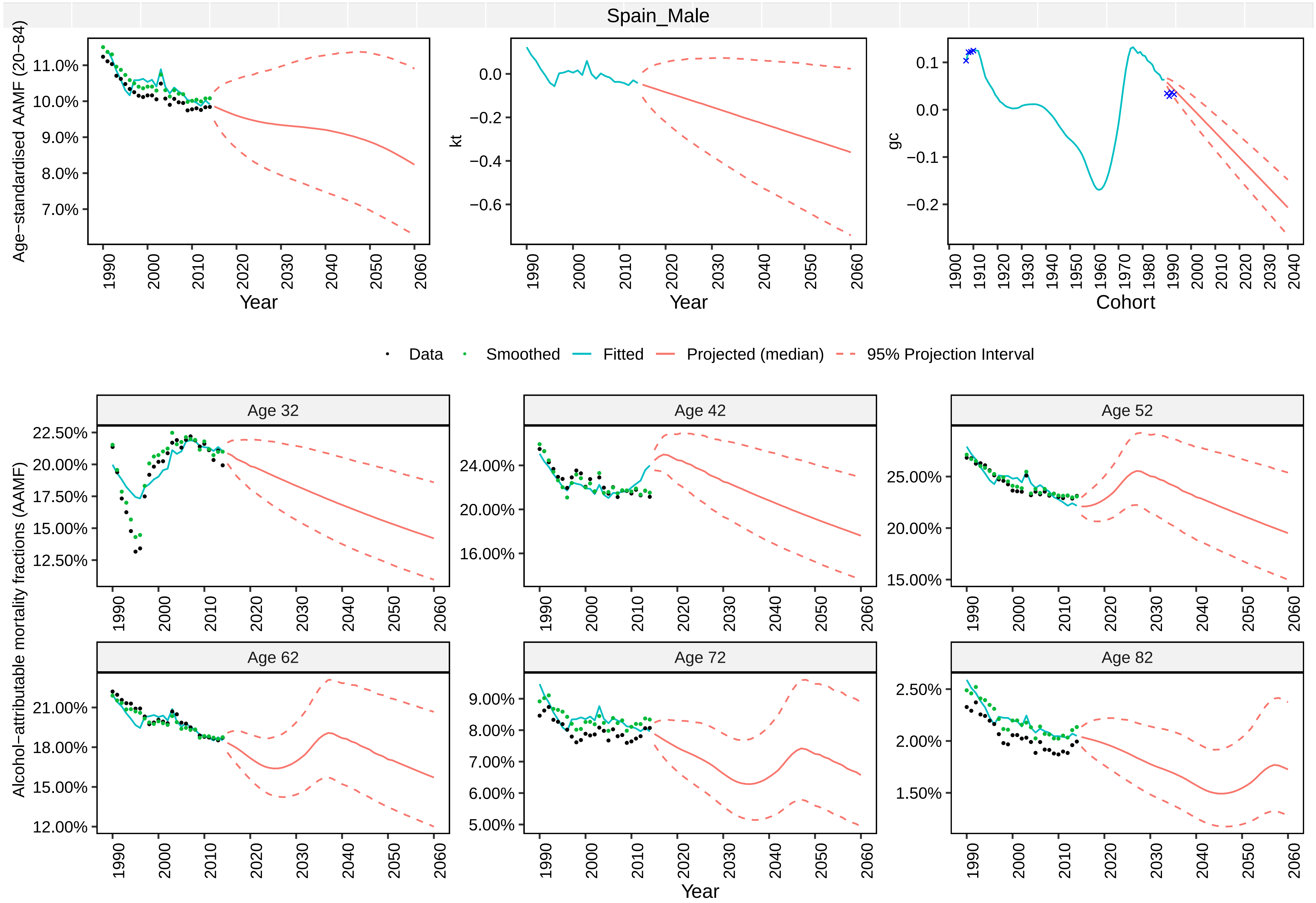


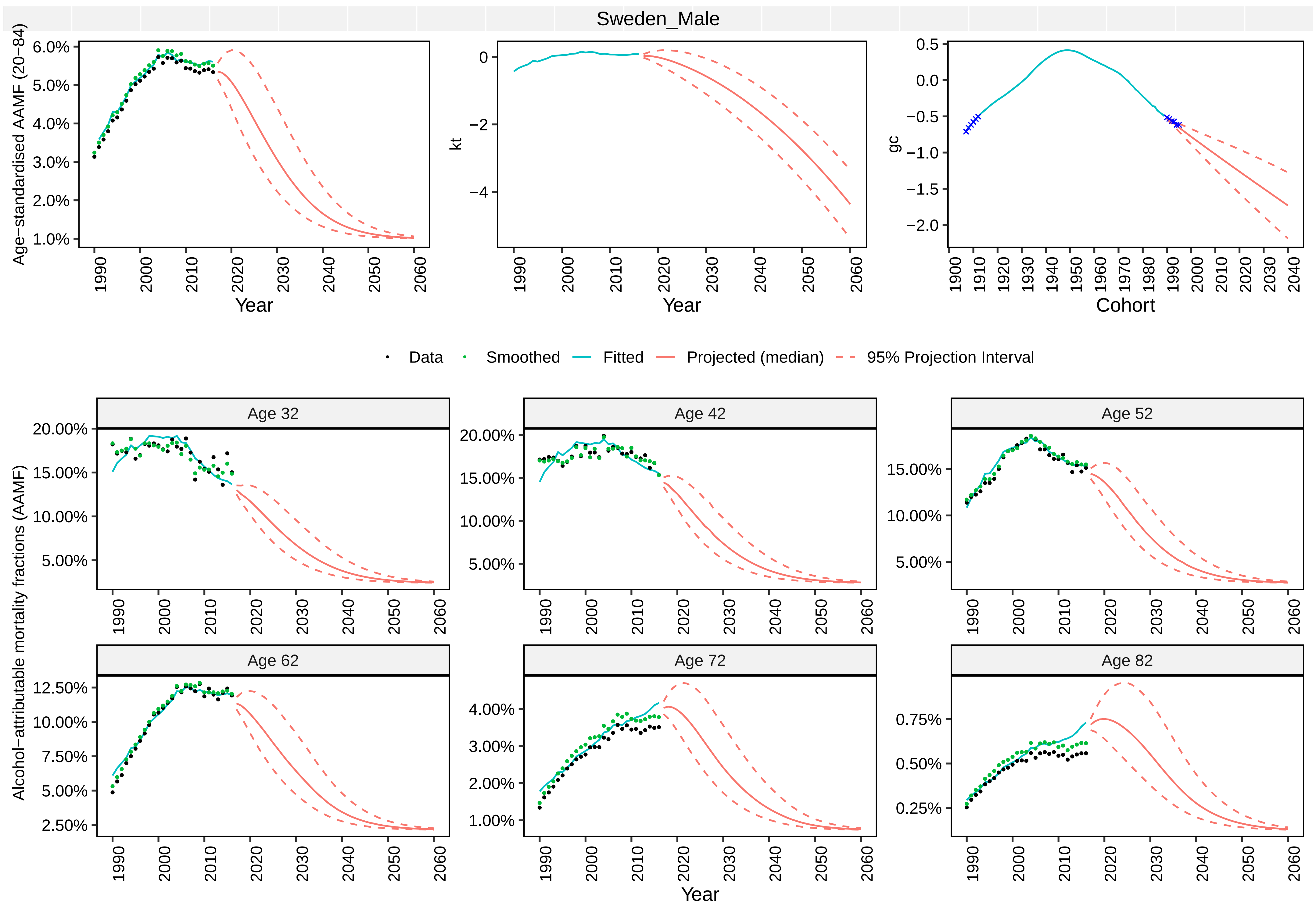
Portugal_Male
Age−standardised AAMF (20−84)
14.0%
12.0%
10.0%
Year
kt
0.0
−0.2
−0.4
−0.6
gc
0.10
0.05
0.00
−0.05
−0.10
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Year


Russia_Male
Age−standardised AAMF (20−84)
kt
gc
Year
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

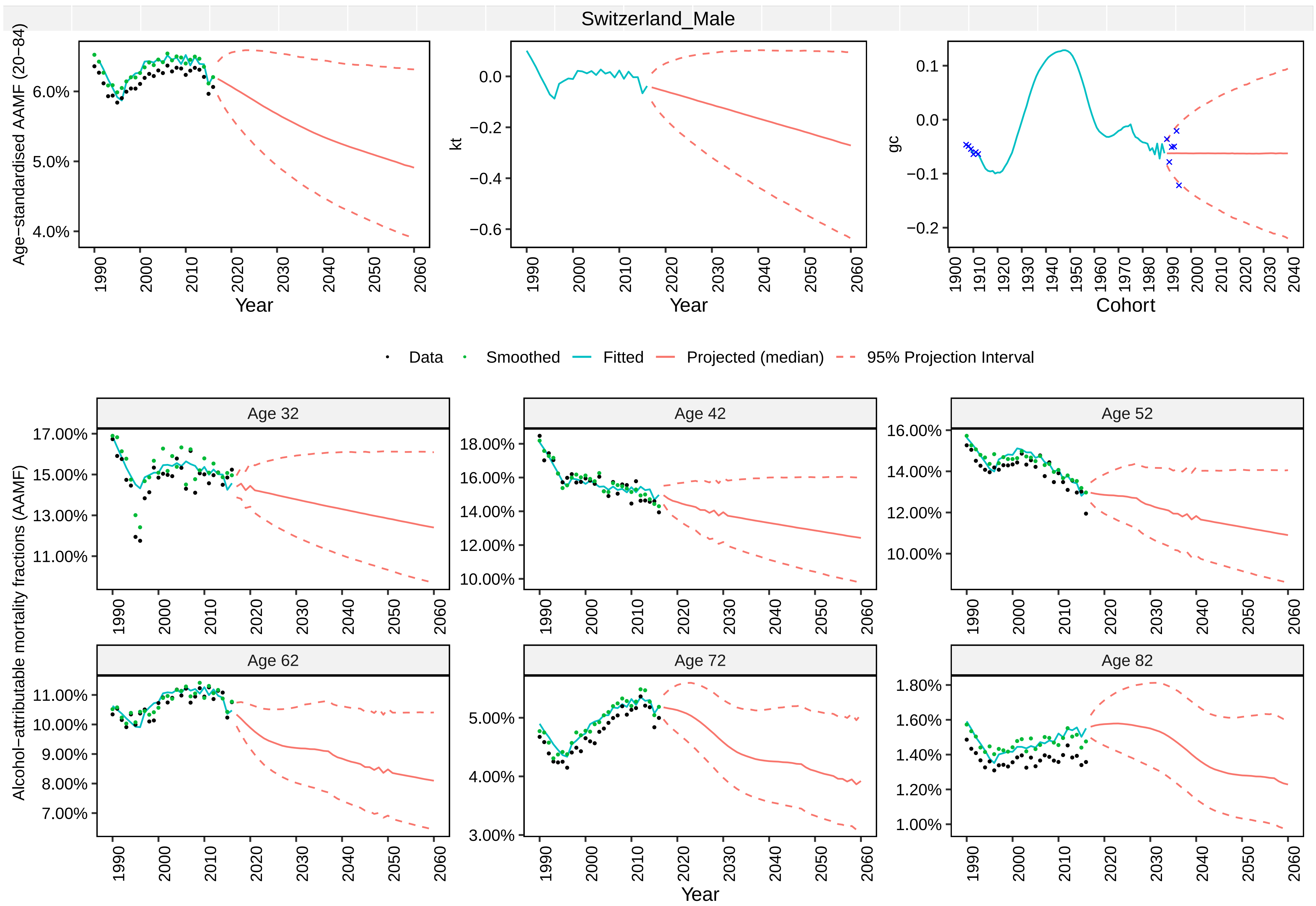


Slovenia_Male
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

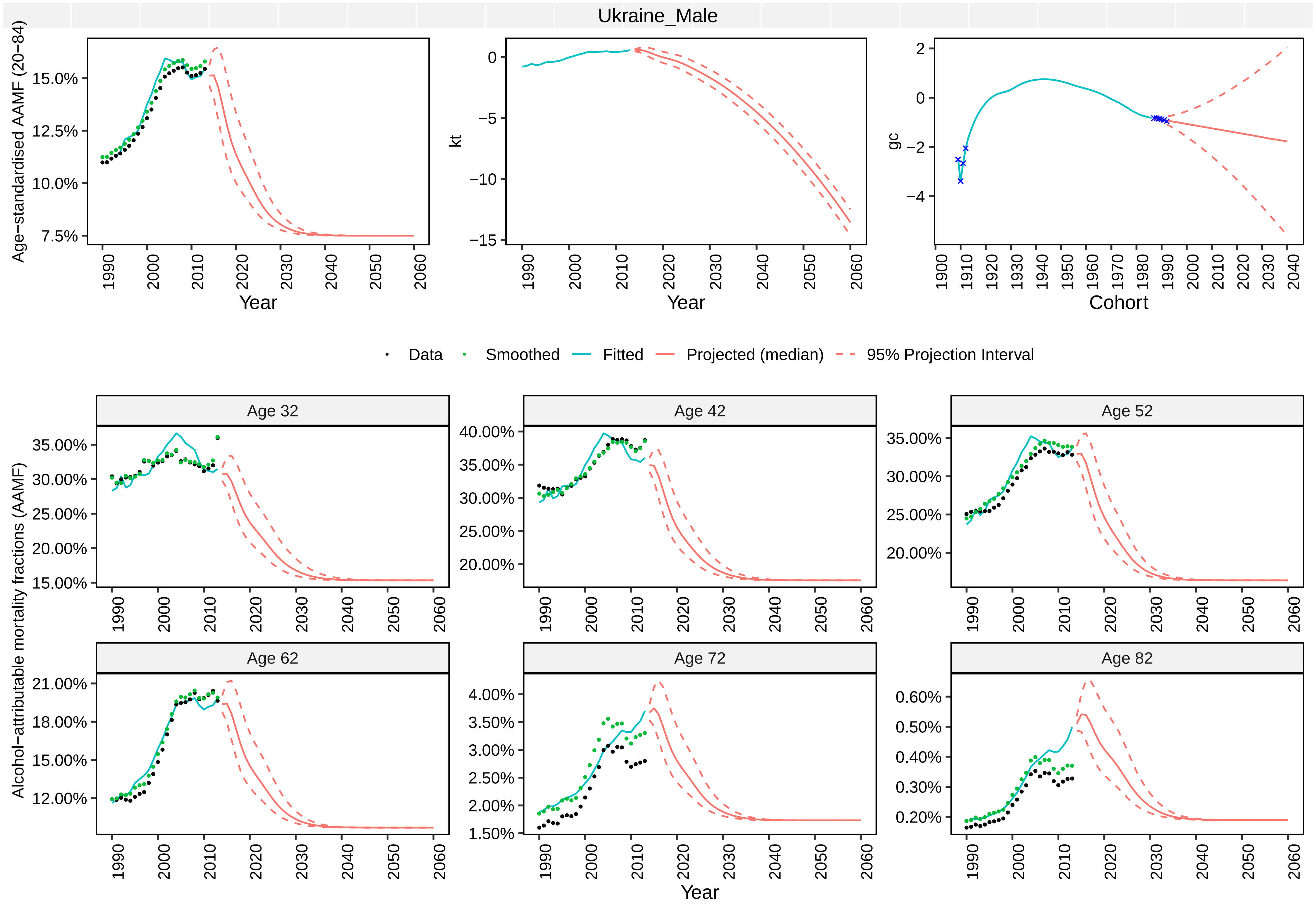

Spain_Male
Age−standardised AAMF (20−84)
kt
gc
Year
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



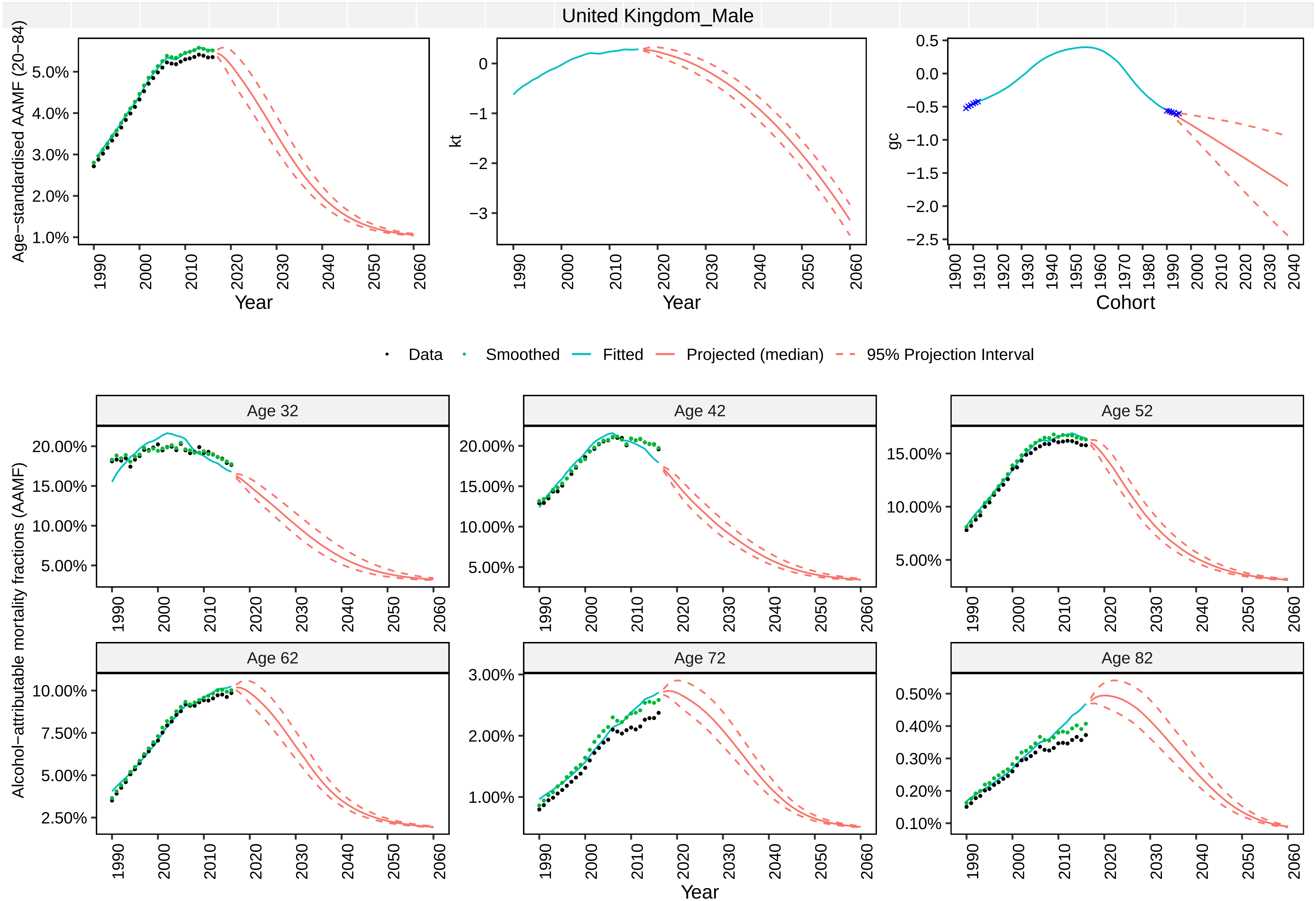
Sweden_Male
Age−standardised AAMF (20−84)
6.0%
5.0%
4.0%
3.0%
2.0%
1.0%
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

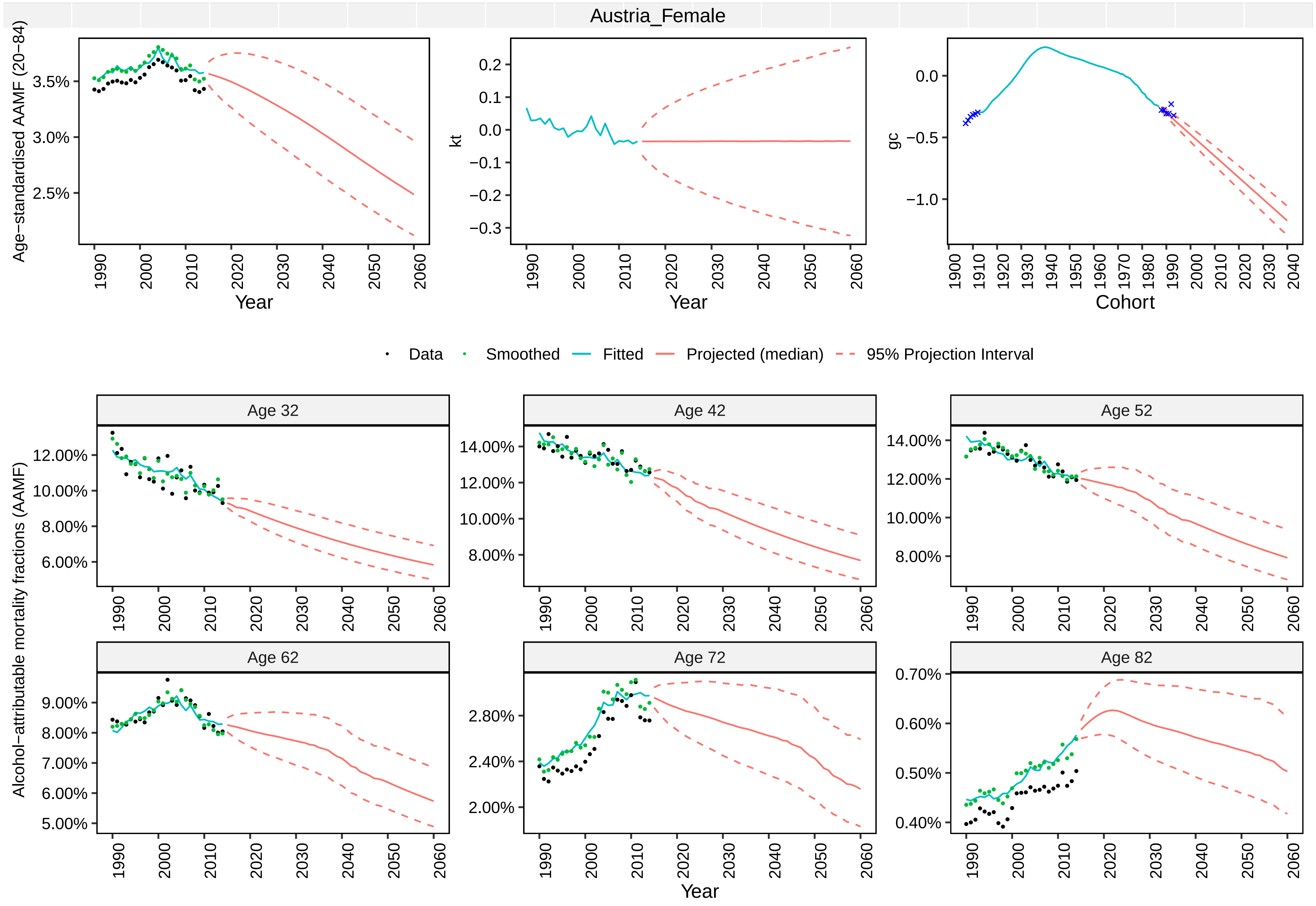


Switzerland_Male
Age−standardised AAMF (20−84)
6.0%
5.0%
4.0%
Year
kt
0.0
−0.2
−0.4
−0.6
gc
0.1
0.0
−0.1
−0.2
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
1990
2000
2010
2020
2030
2040
2050
2060
Year

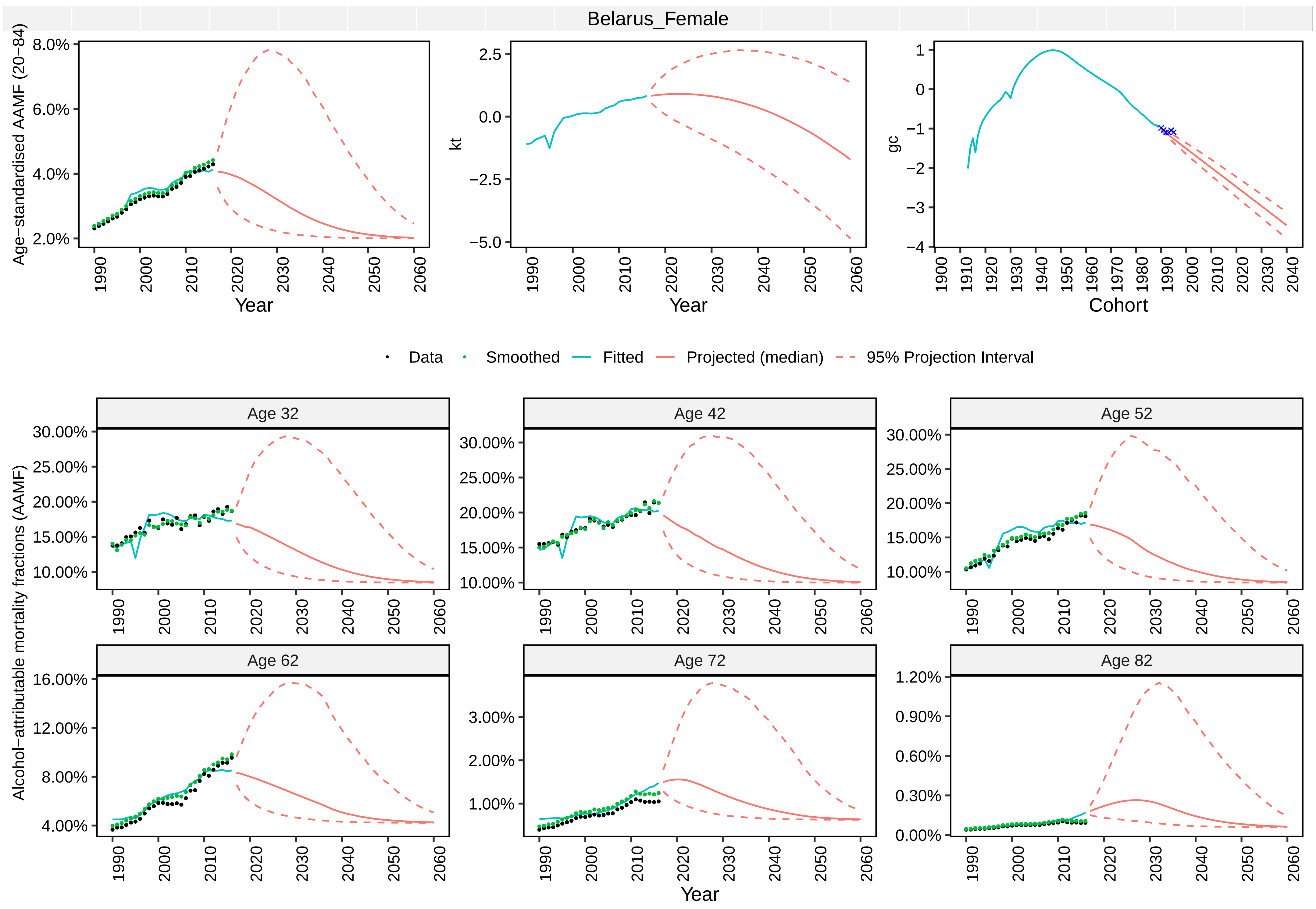


Ukraine_Male
Age−standardised AAMF (20−84)
15.0%
12.5%
10.0%
7.5%
Year
kt
0
−5
−10
−15
Year
gc
2
0
−2
−4
Cohort
1990
2000
2010
2020
2030
2040
2050
2060
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
35.00%
30.00%
25.00%
20.00%
15.00%
40.00%
21.00%
18.00%
15.00%
12.00%
4.00%
3.50%
3.00%
2.50%
2.00%
1.50%
0.60%
0.50%
0.40%
0.30%
0.20%
Year

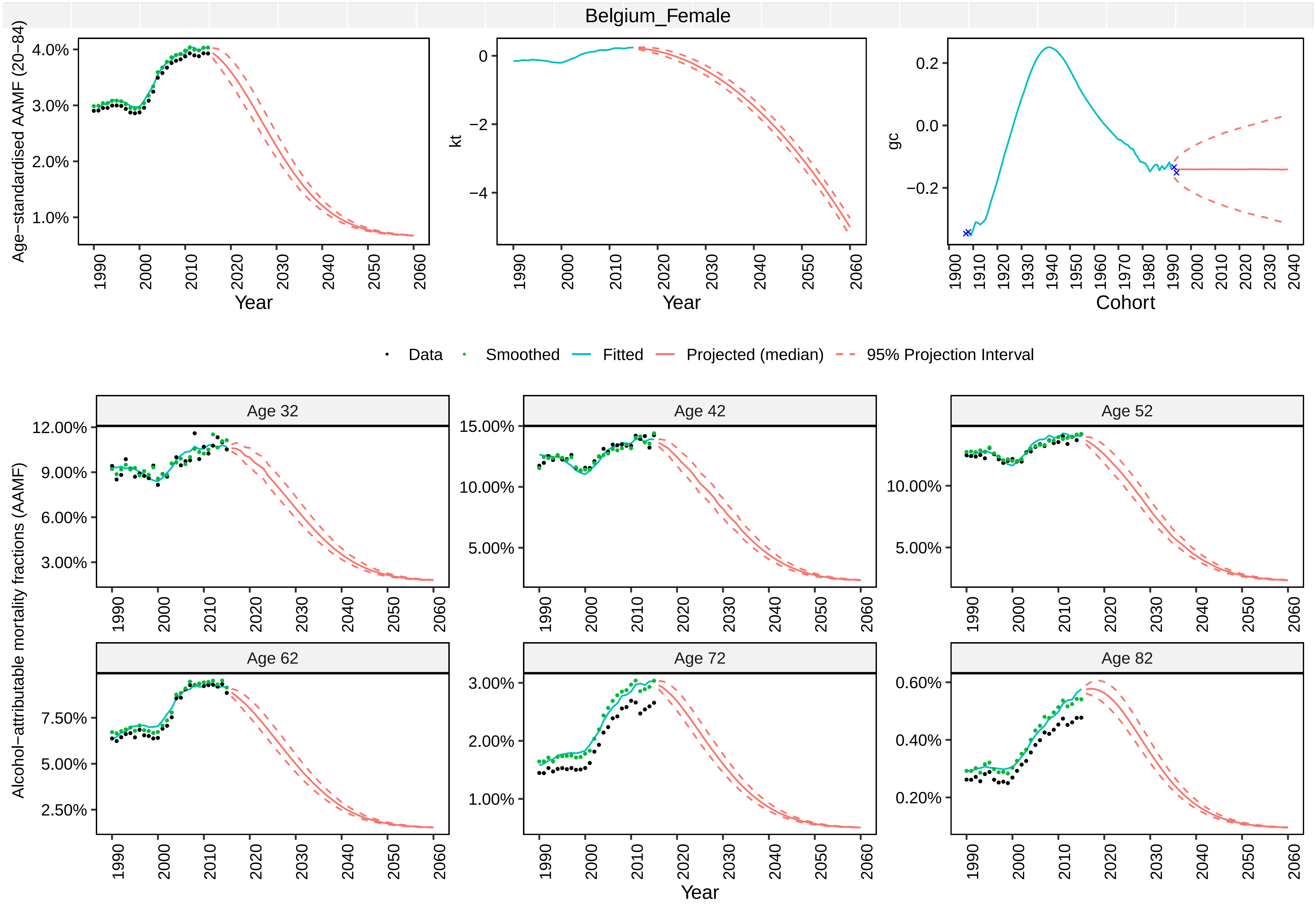

United Kingdom_Male
Age−standardised AAMF (20−84)
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



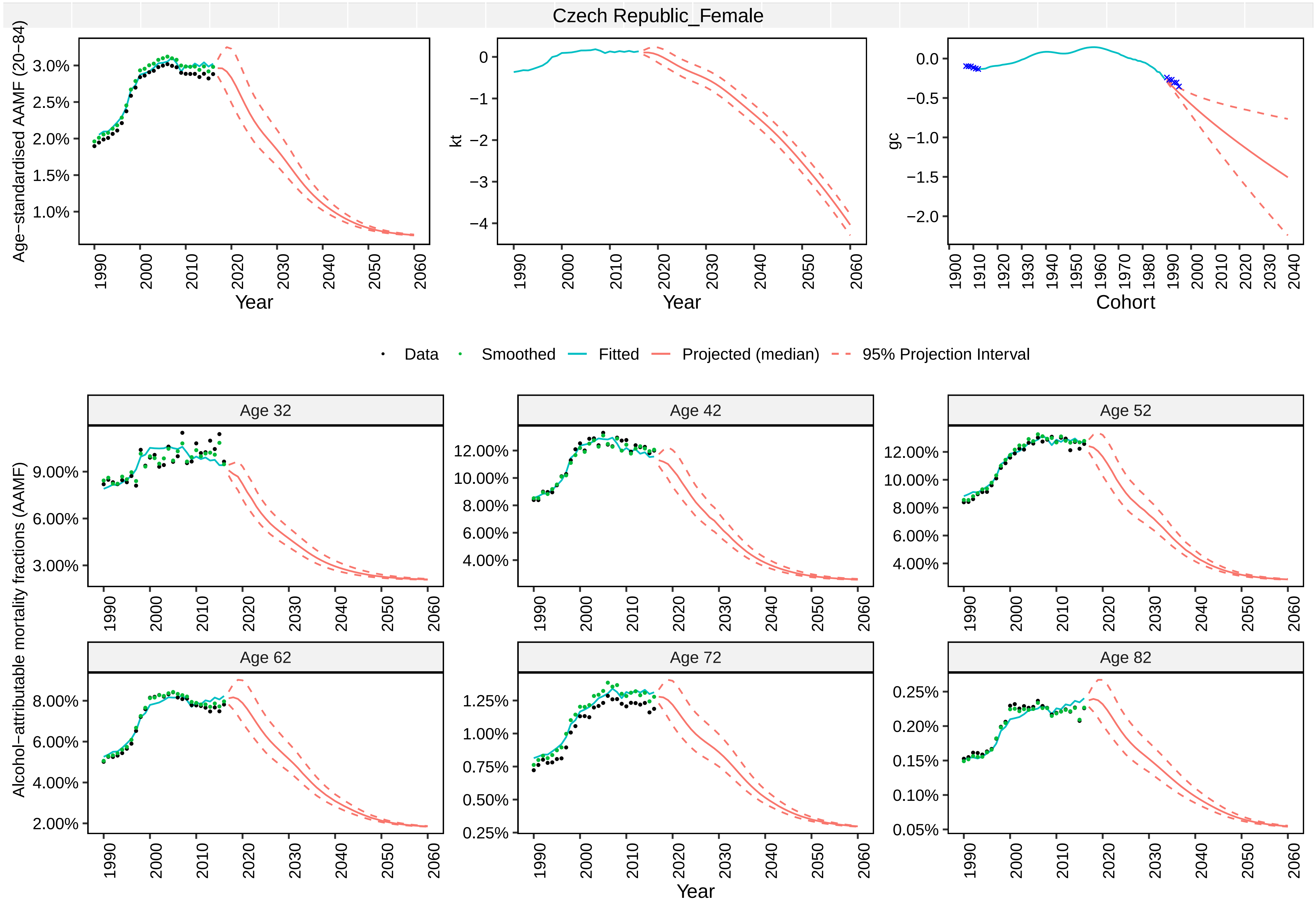
Austria_Female
Age−standardised AAMF (20−84)
3.5%
3.0%
2.5%
Year
kt
0.2
0.1
0.0
−0.1
−0.2
−0.3
gc
0.0
−0.5
−1.0
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
12.00%
10.00%
8.00%
6.00%
14.00%
9.00%
7.00%
5.00%
2.80%
2.40%
2.00%
0.70%
0.60%
0.50%
0.40%
1990
2000
2010
2020
2030
2040
2050
2060
Year



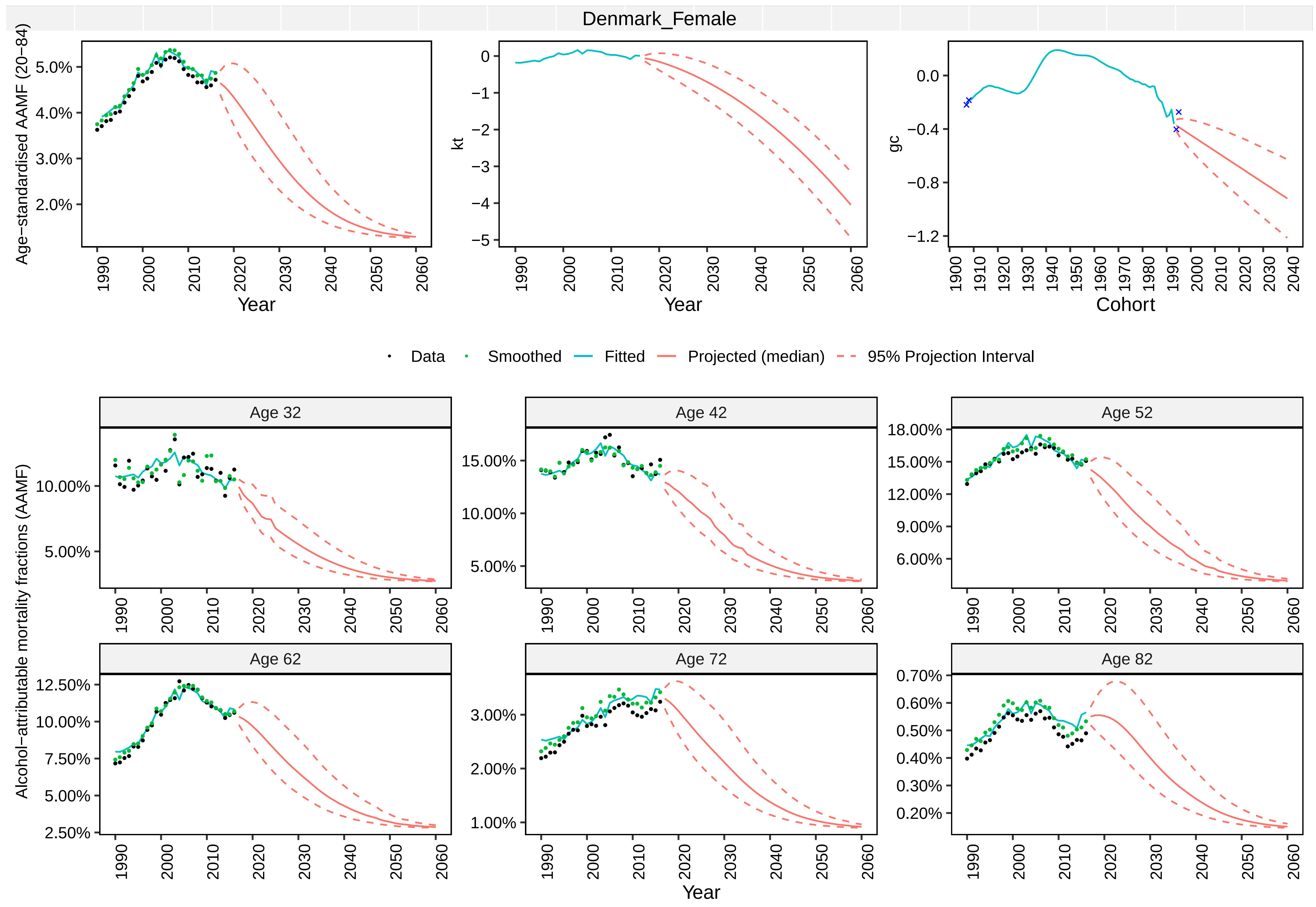
Belarus_Female
Age−standardised AAMF (20−84)
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



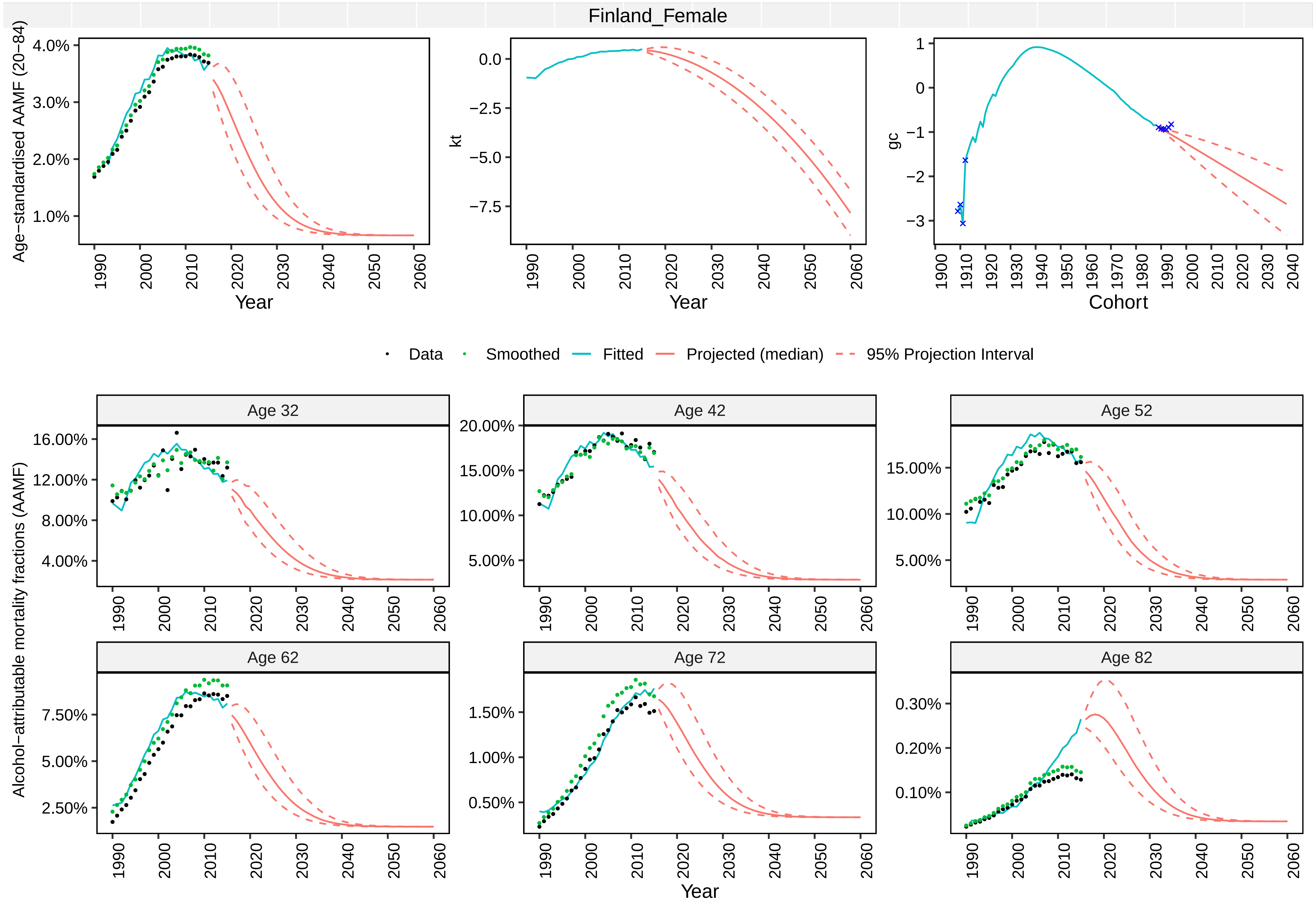
Belgium_Female
Age−standardised AAMF (20−84)
4.0%
3.0%
2.0%
1.0%
Year
kt
0
−2
−4
Year
gc
0.2
0.0
−0.2
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
12.00%
9.00%
6.00%
3.00%
15.00%
10.00%
5.00%
7.50%
2.50%
3.00%
2.00%
1.00%
0.60%
0.40%
0.20%
Year

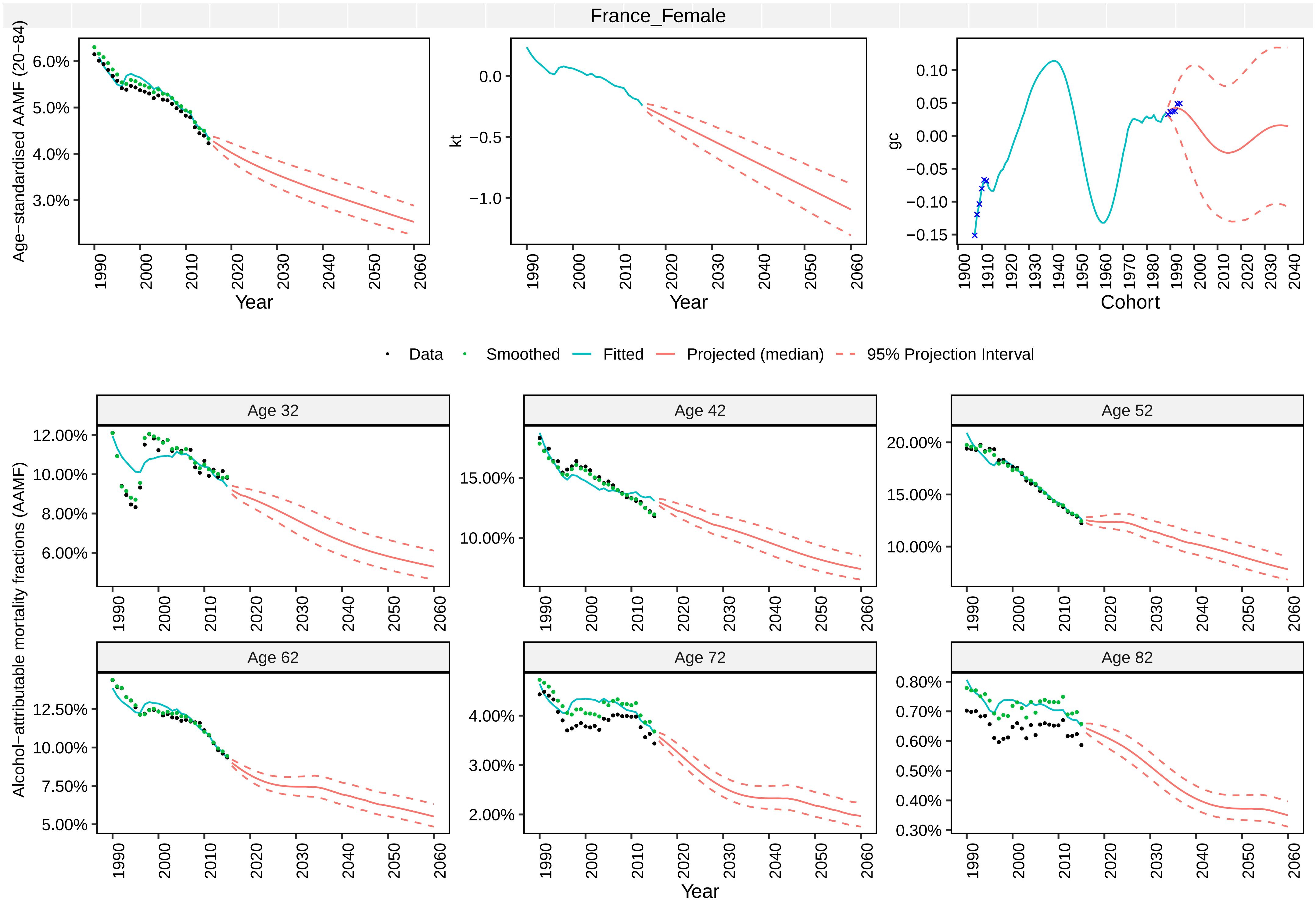


Czech Republic_Female
Age−standardised AAMF (20−84)
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

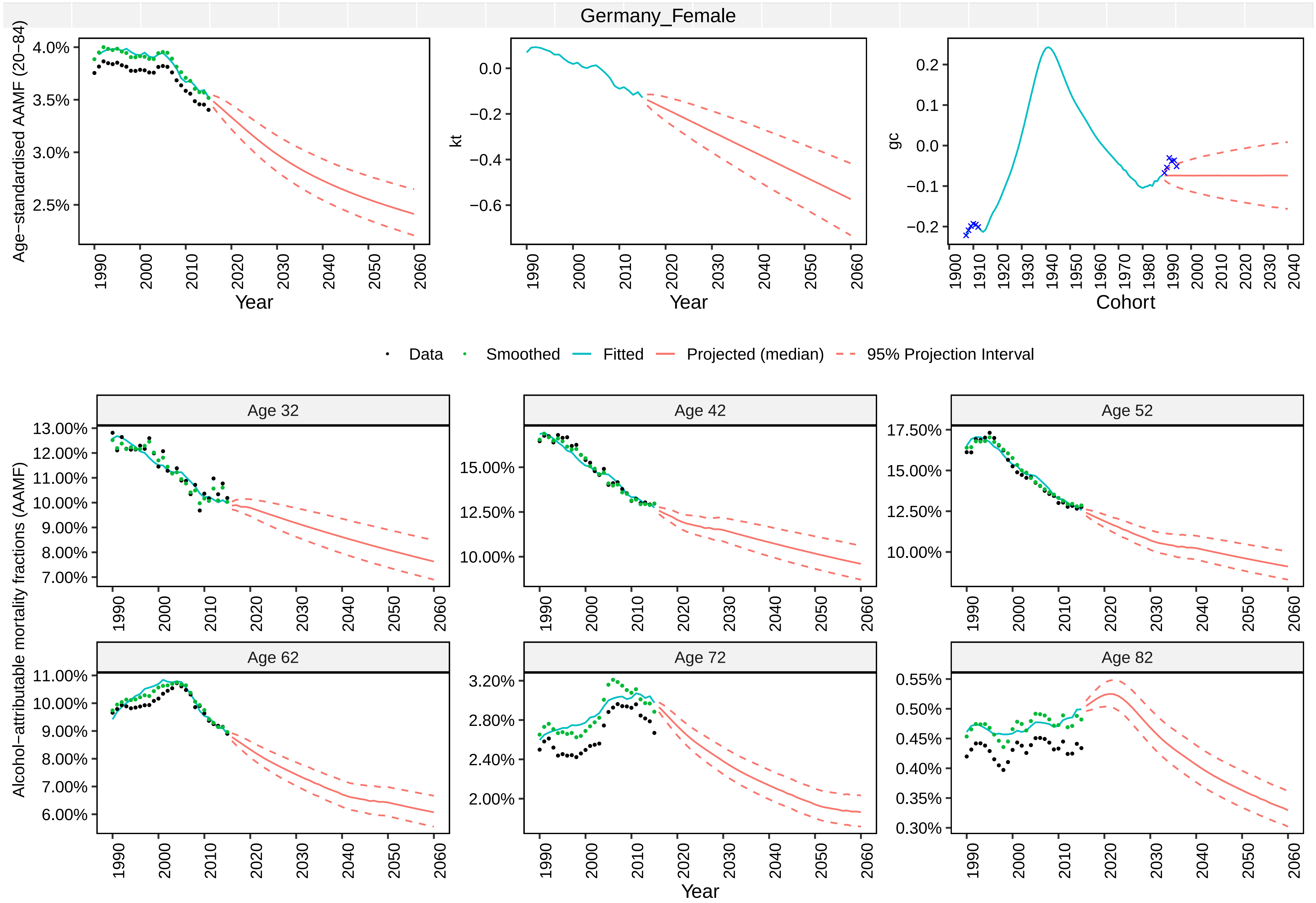


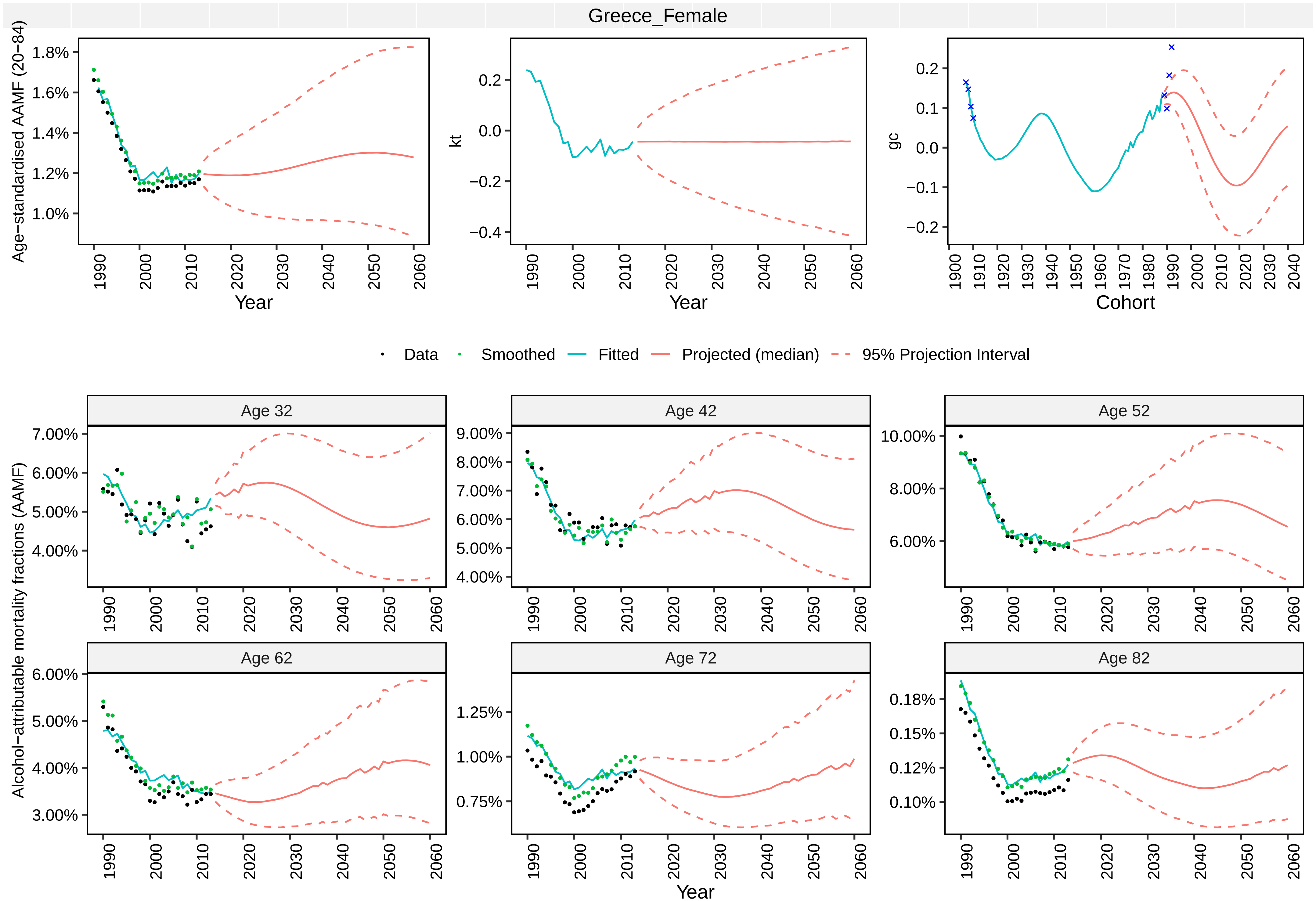
Denmark_Female
Age−standardised AAMF (20−84)
kt
gc
Year
Year
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year


Finland_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

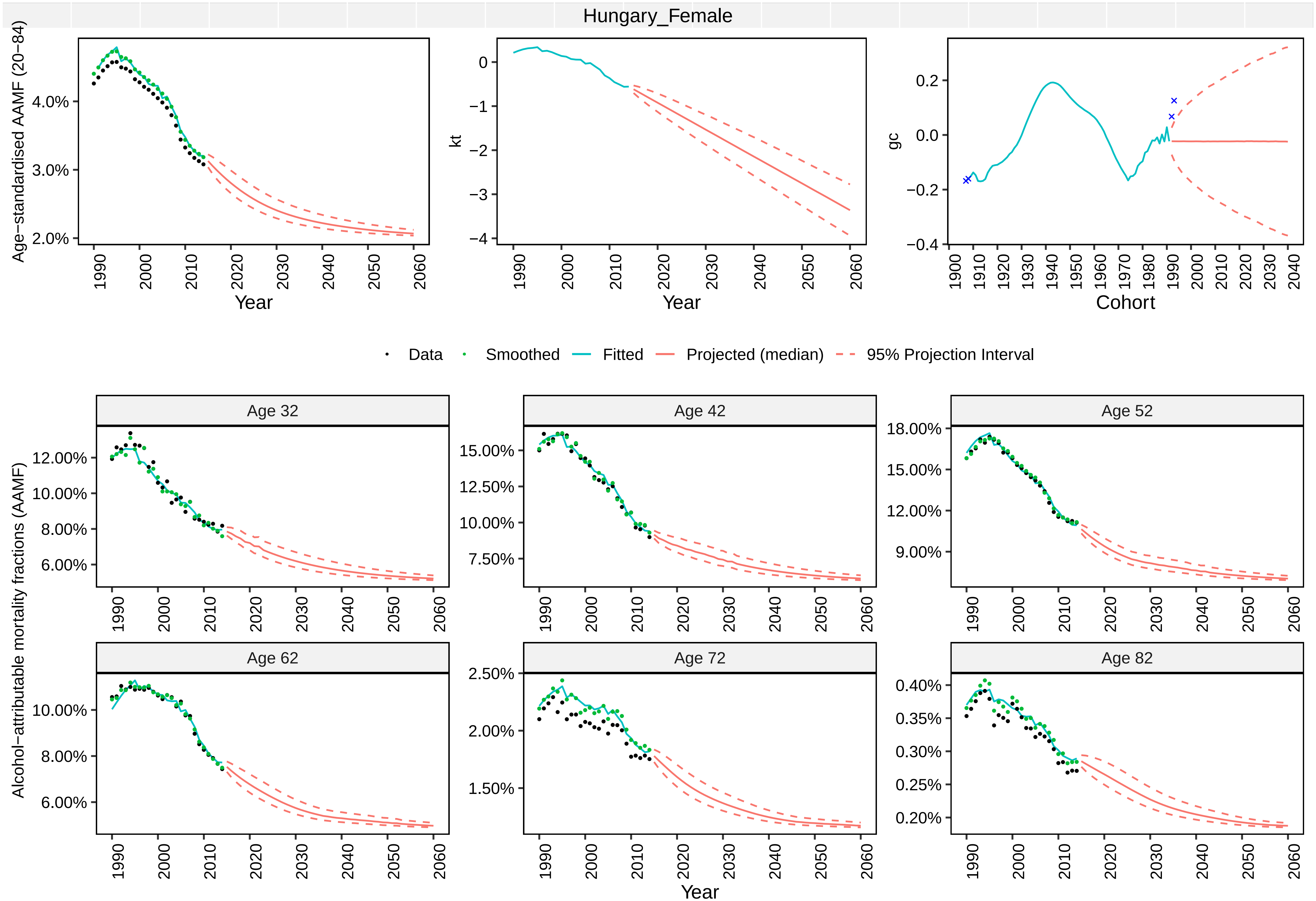


France_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

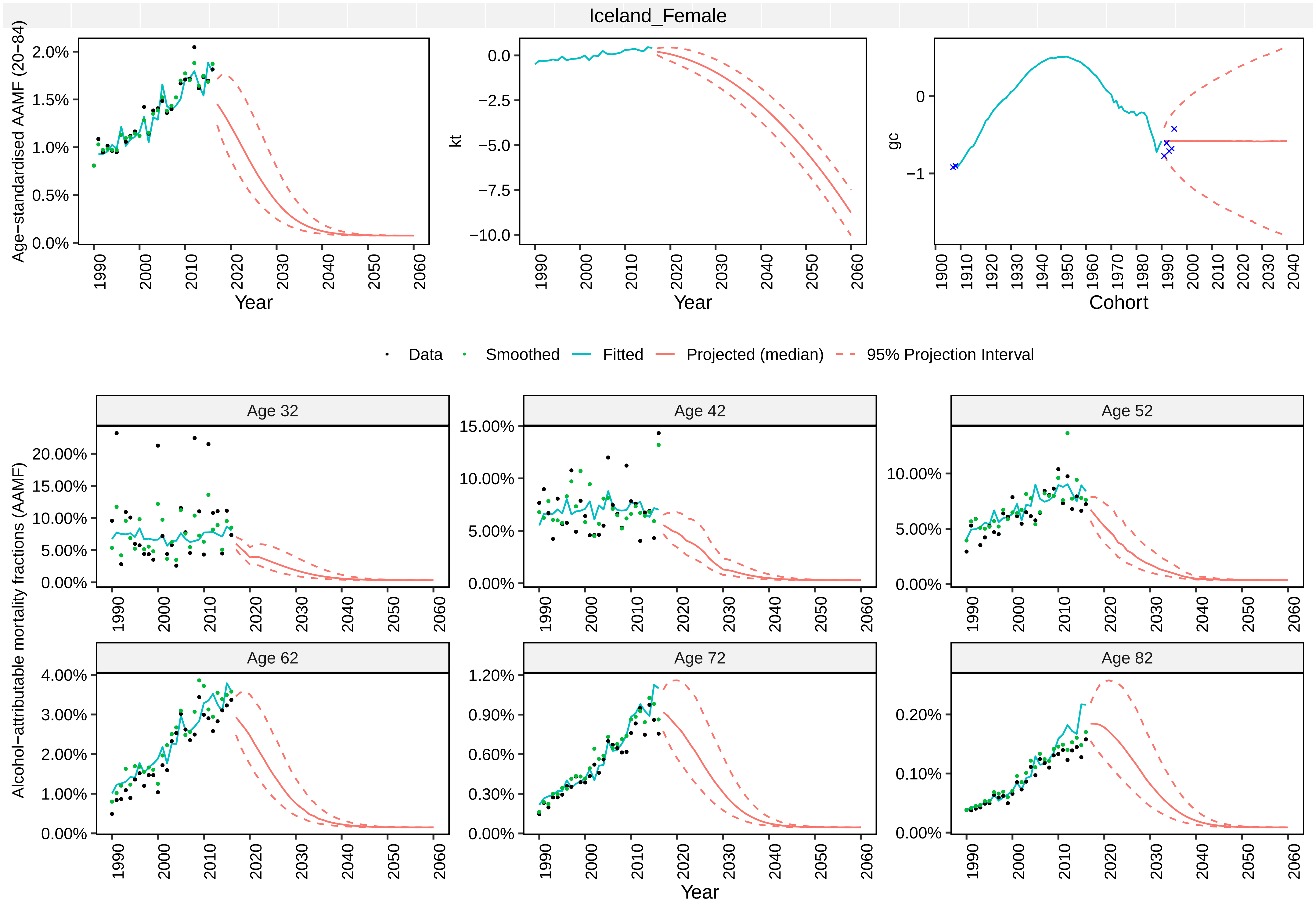

Germany_Female
Age−standardised AAMF (20−84)
kt
gc
Year
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



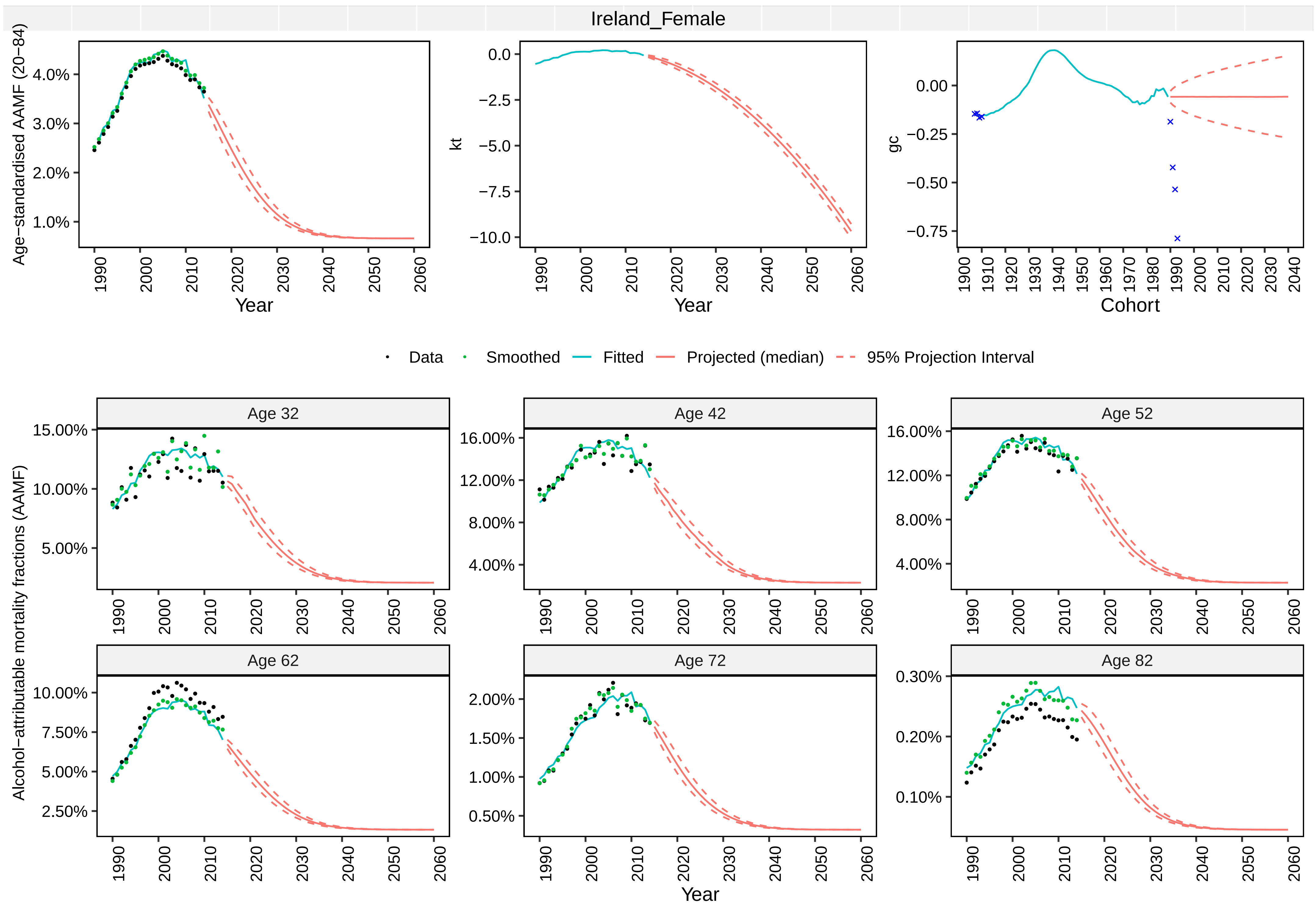
Greece_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)



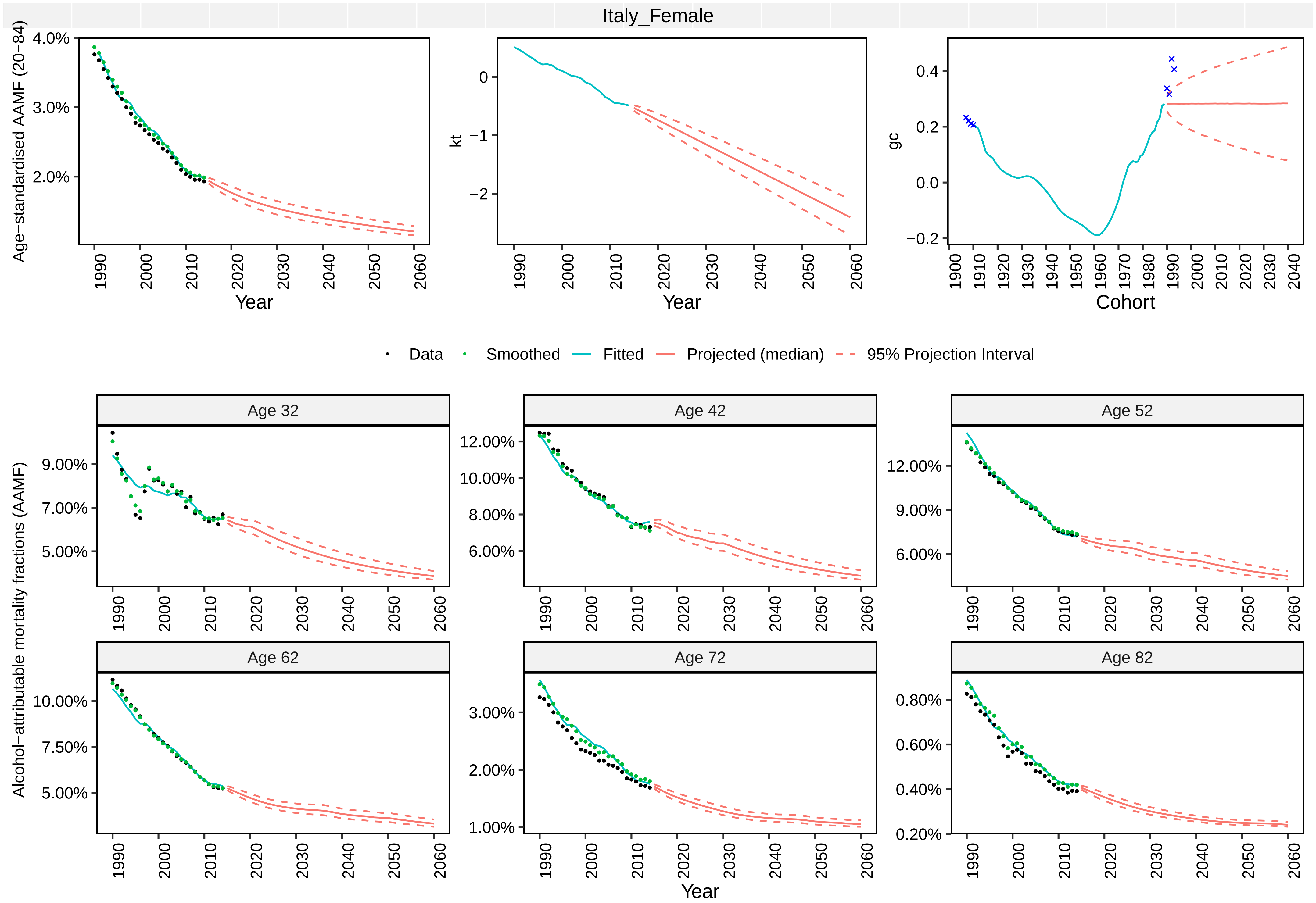
Hungary_Female
Age−standardised AAMF (20−84)
4.0%
3.0%
2.0%
Year
kt
0
−1
−2
−3
−4
gc
0.2
0.0
−0.2
−0.4
Cohort
1990
2000
2010
2020
2030
2040
2050
2060
1900
1910
1920
1930
1940
1950
1960
1970
1980
2040
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
12.00%
10.00%
8.00%
6.00%
Age 42
15.00%
12.50%
10.00%
7.50%
Age 52
18.00%
15.00%
12.00%
9.00%
Age 62
10.00%
8.00%
6.00%
Age 72
2.50%
2.00%
1.50%
Age 82
0.40%
0.35%
0.30%
0.25%
0.20%



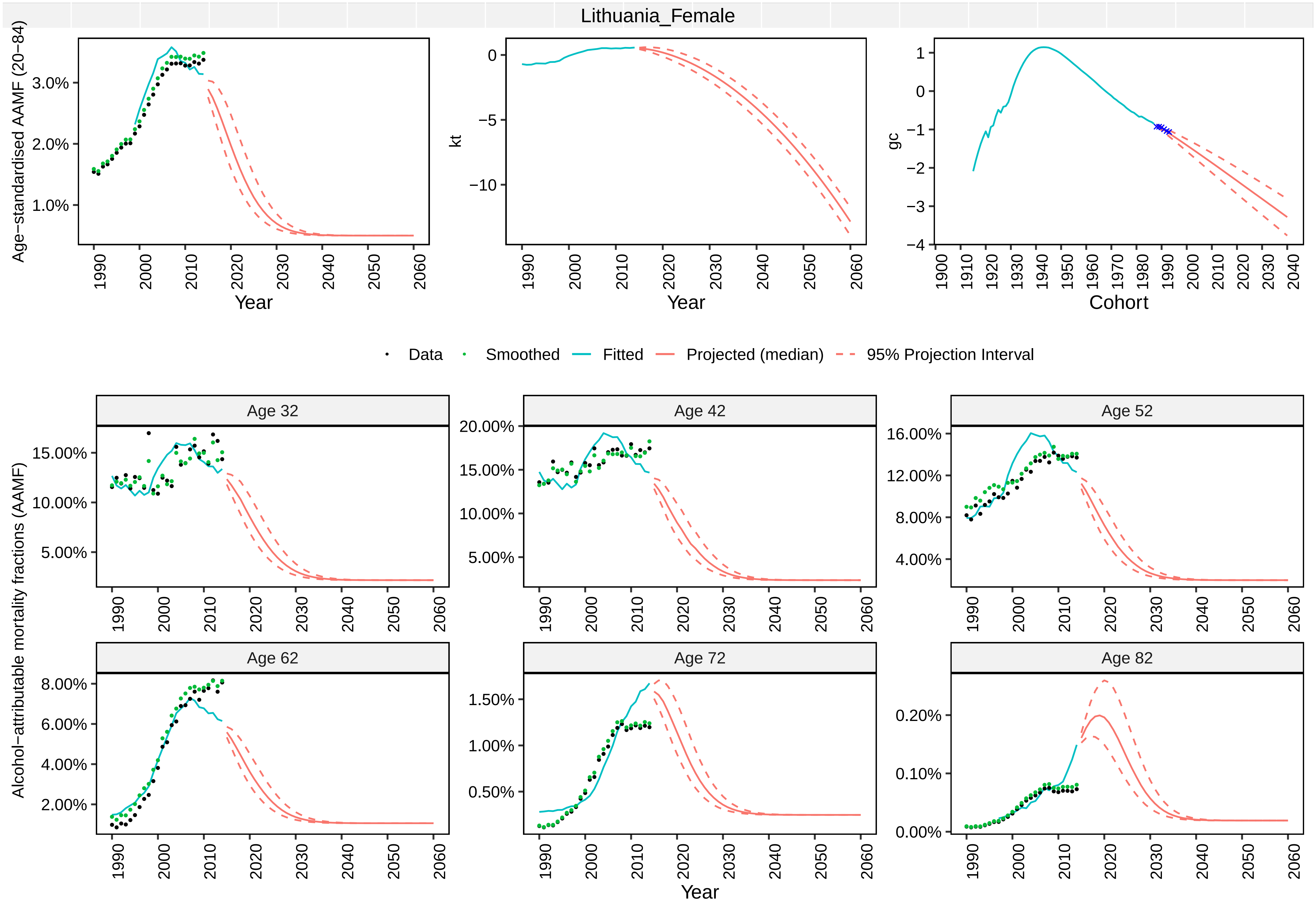
Iceland_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)

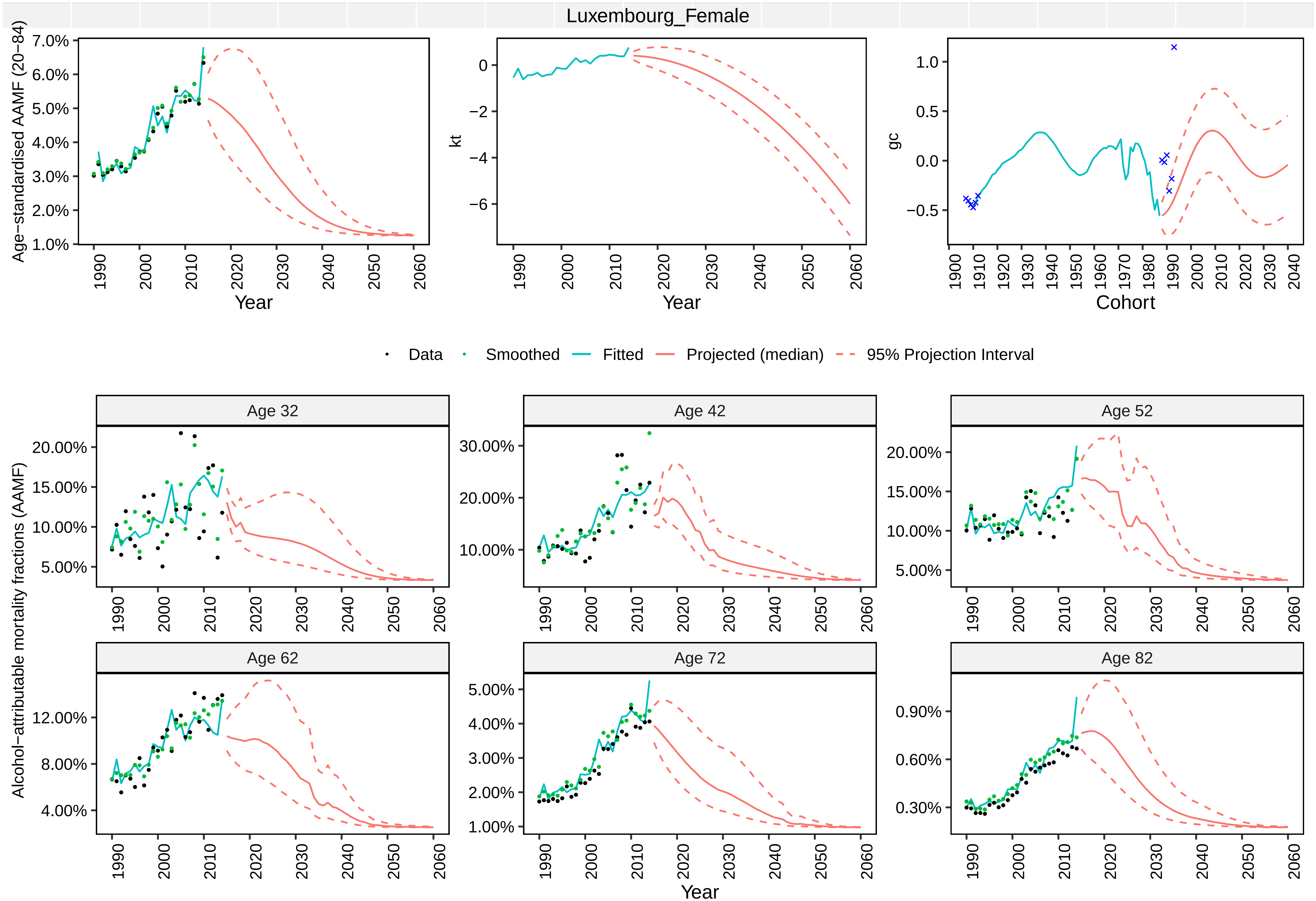


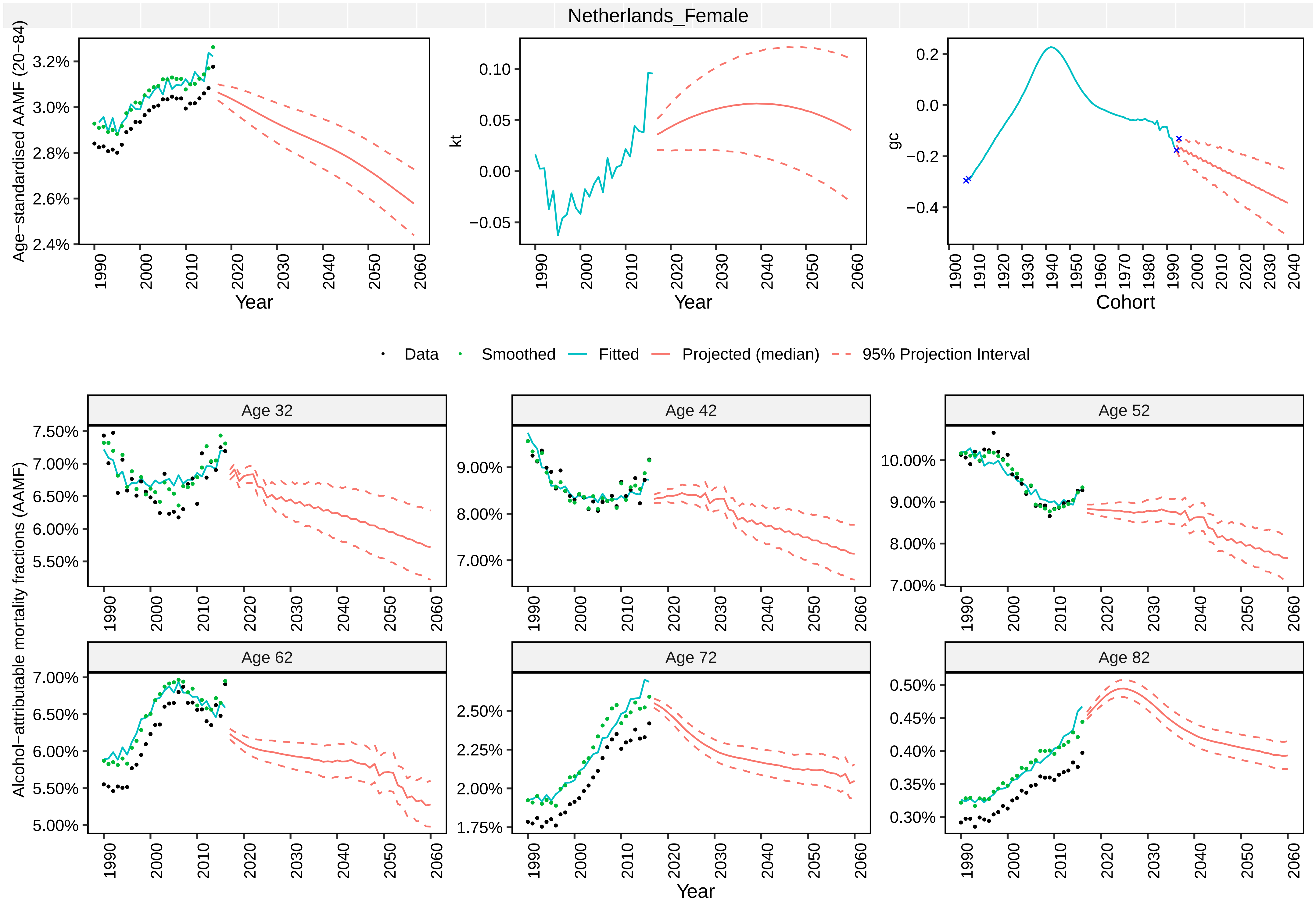
Ireland_Female
Age−standardised AAMF (20−84)
4.0%
3.0%
2.0%
1.0%
Year
kt
0.0
−2.5
−5.0
−7.5
−10.0
gc
0.00
−0.25
−0.50
−0.75
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
1990
2000
2010
2020
2030
2040
2050
2060



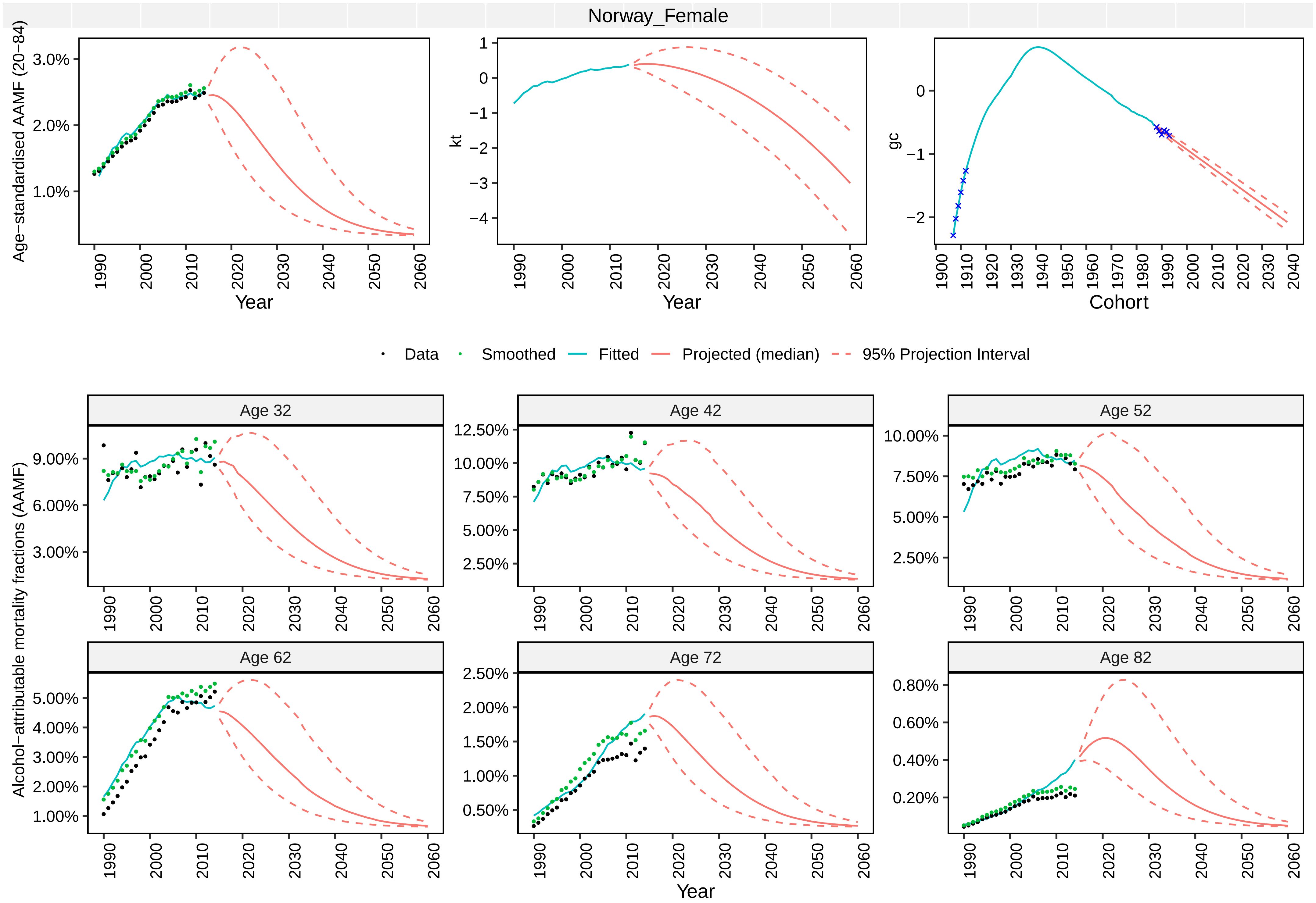
Italy_Female
Age−standardised AAMF (20−84)
4.0%
3.0%
2.0%
Year
kt
0
−1
−2
gc
0.4
0.2
0.0
−0.2
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
9.00%
7.00%
5.00%
12.00%
10.00%
8.00%
6.00%
12.00%
9.00%
6.00%
10.00%
7.50%
5.00%
3.00%
2.00%
1.00%
0.80%
0.60%
0.40%
0.20%
1990
2000
2010
2020
2030
2040
2050
2060
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
Year

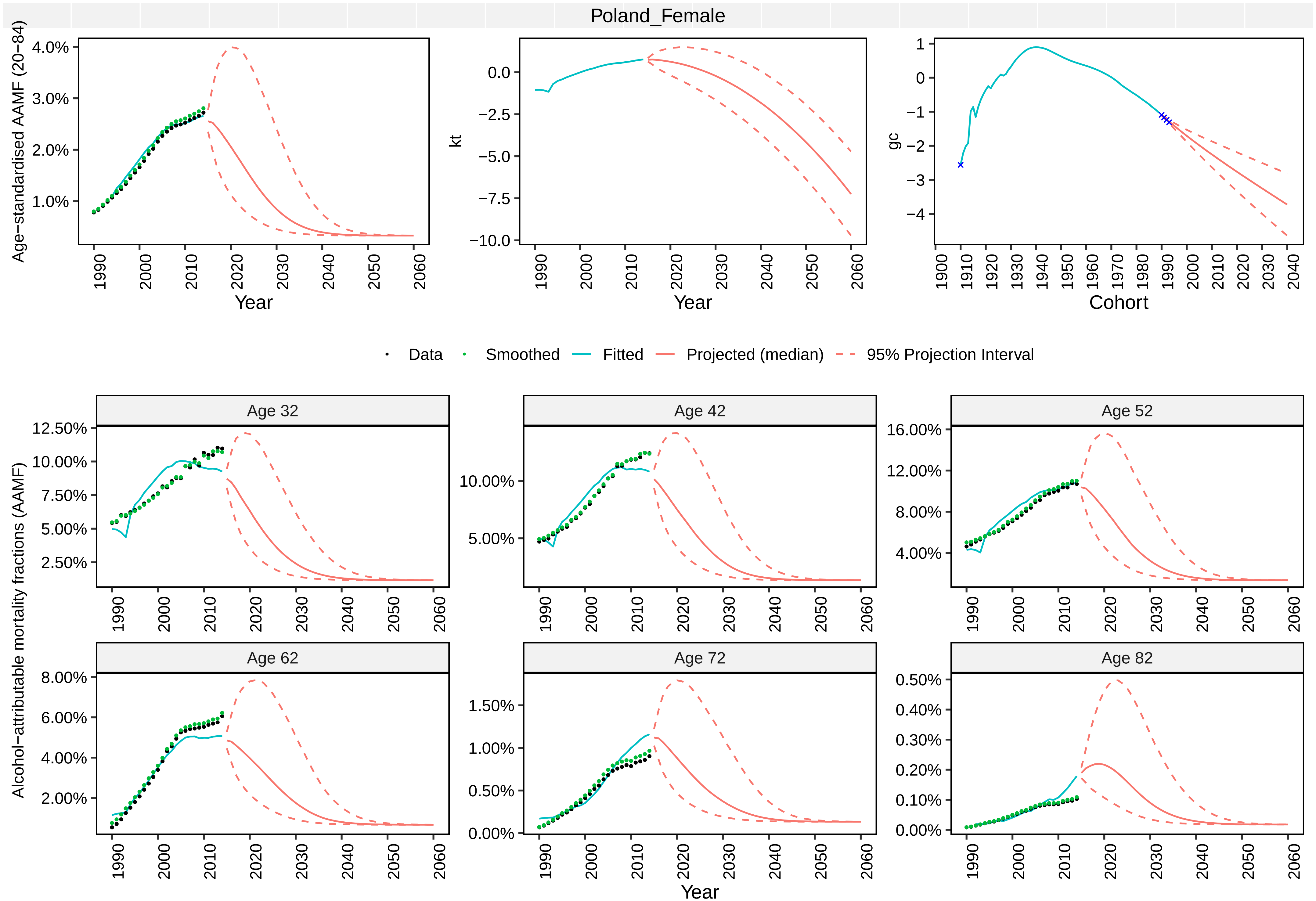

Lithuania_Female
Age−standardised AAMF (20−84)
3.0%
2.0%
1.0%
Year
kt
0
−5
−10
gc
1
0
−1
−2
−3
−4
Cohort
1990
2000
2010
2020
2030
2040
2050
2060
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
2040
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
15.00%
10.00%
5.00%
Age 42
20.00%
15.00%
10.00%
5.00%
Age 52
16.00%
12.00%
8.00%
4.00%
Age 62
8.00%
6.00%
4.00%
2.00%
Age 72
1.50%
1.00%
0.50%
Age 82
0.20%
0.10%
0.00%
Year


Luxembourg_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

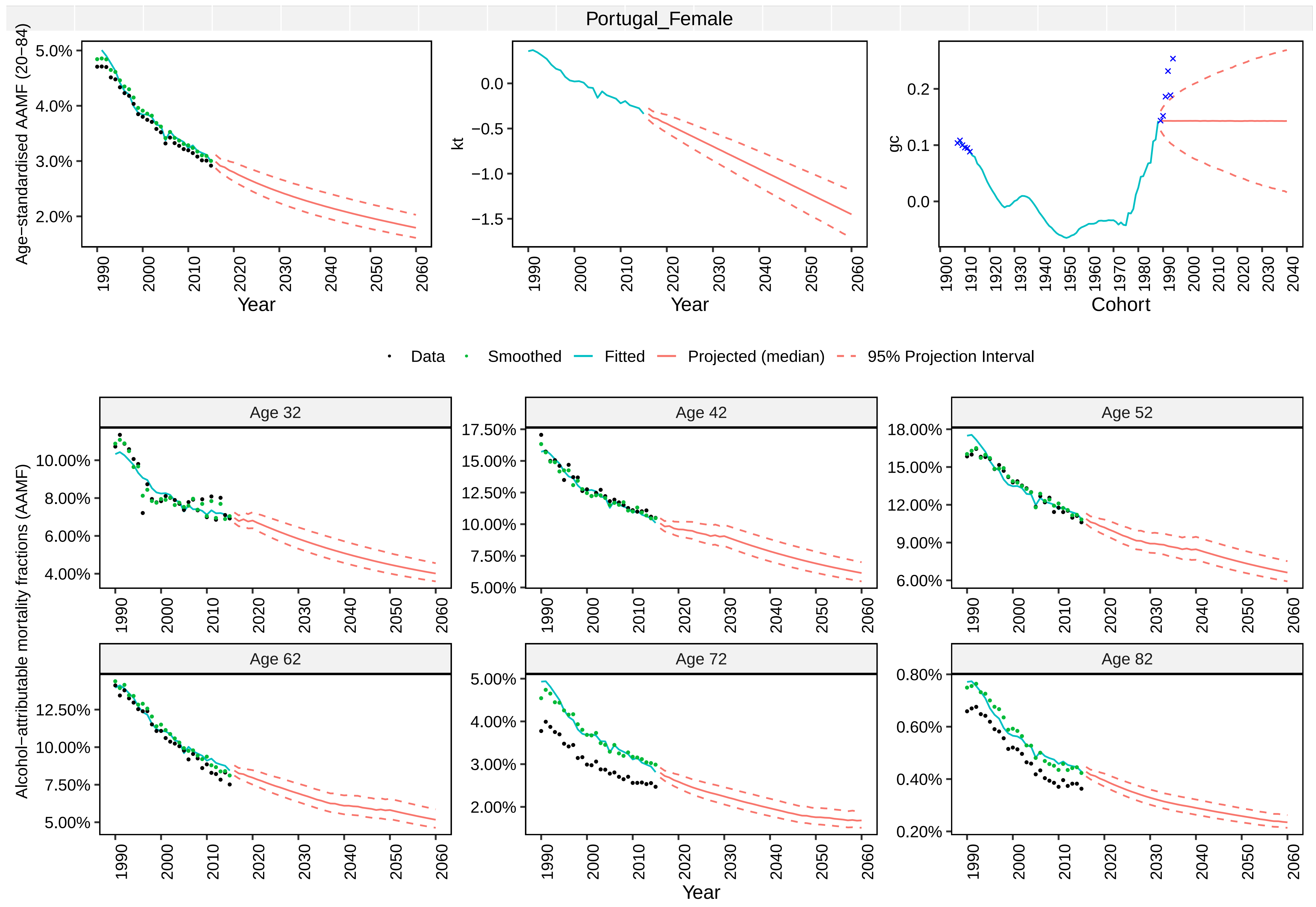


Netherlands_Female
Age−standardised AAMF (20−84)
3.2%
3.0%
2.8%
2.6%
2.4%
Year
kt
0.10
0.05
0.00
−0.05
gc
0.2
0.0
−0.2
−0.4
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Year

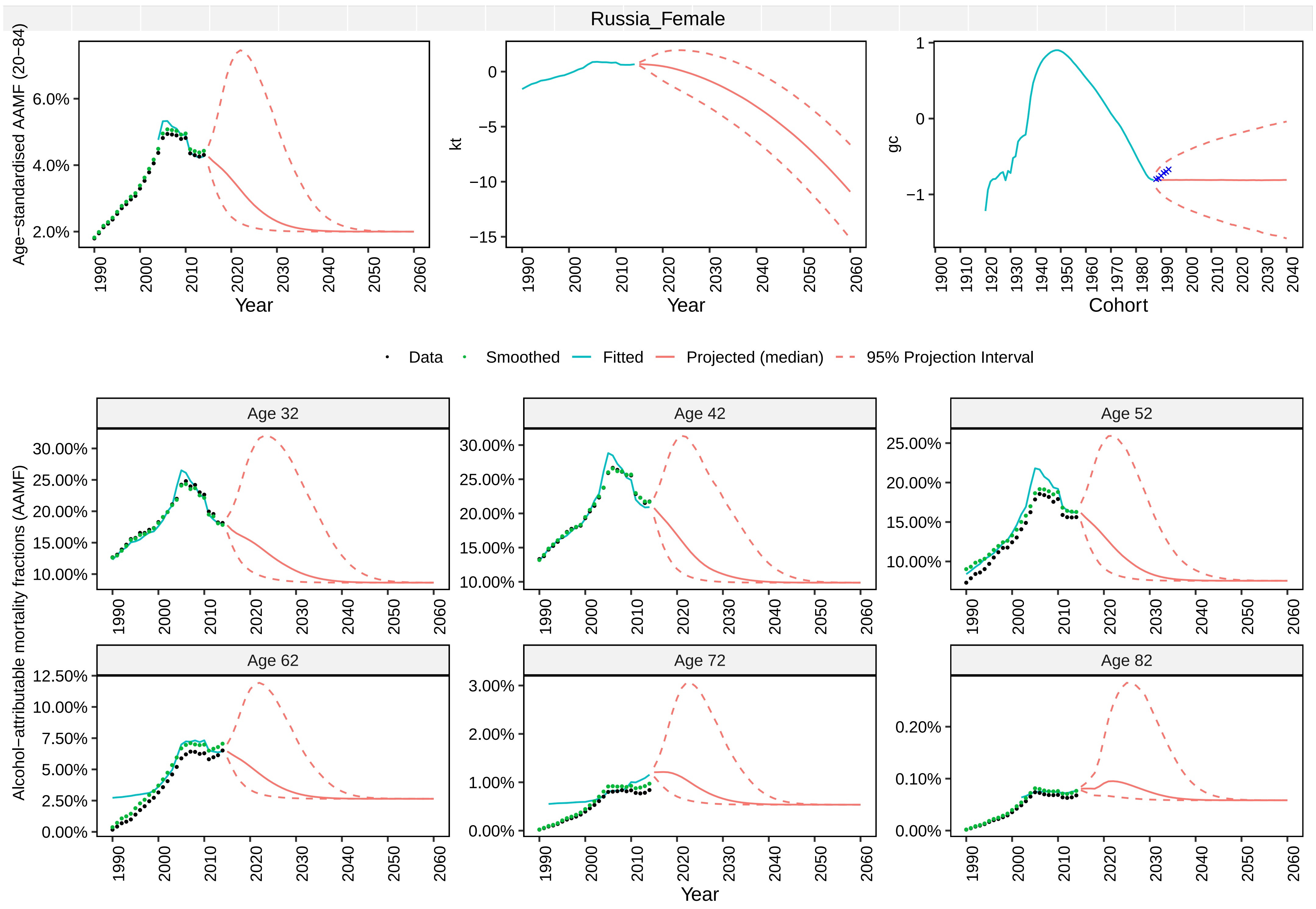

Norway_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



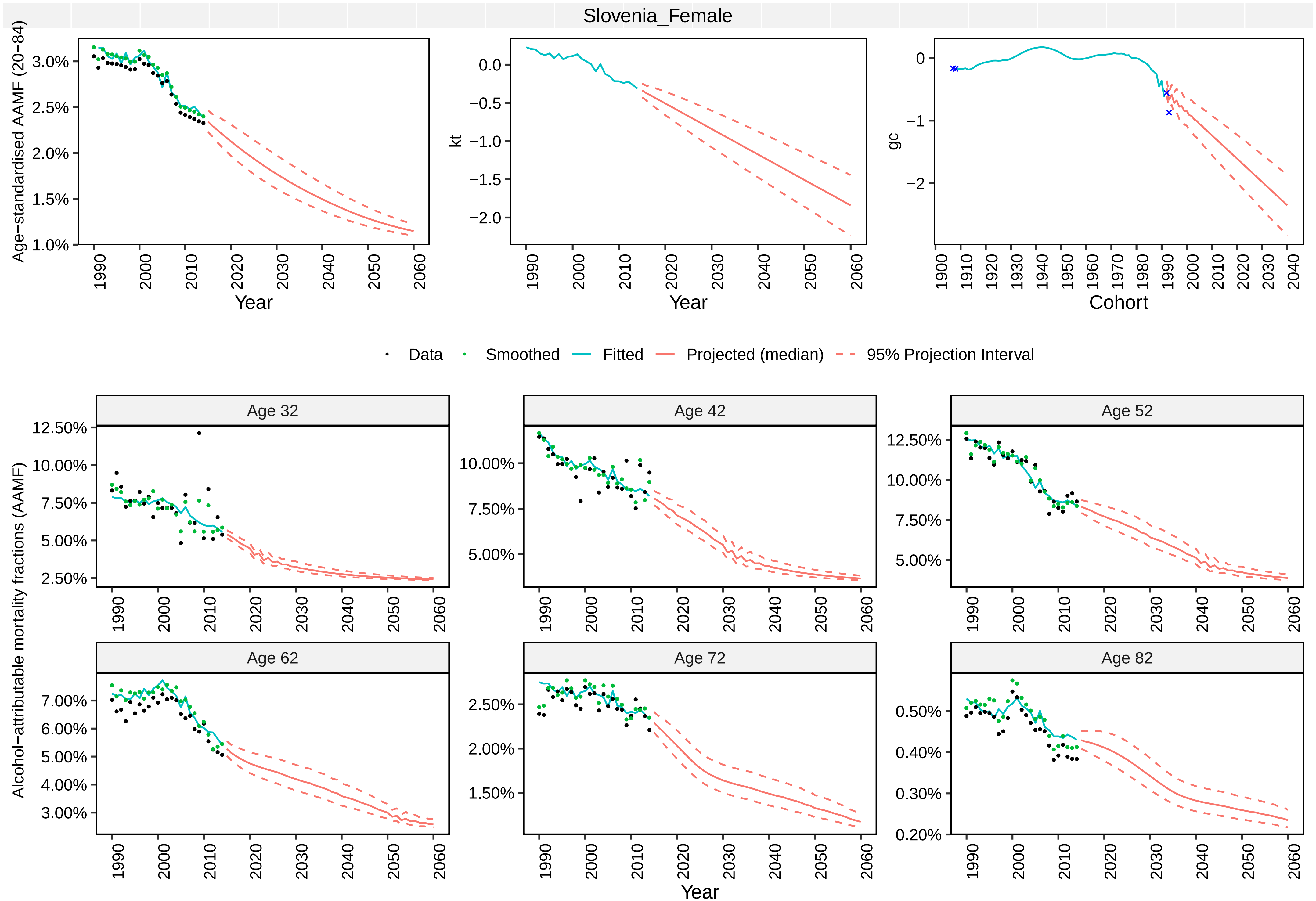
Poland_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



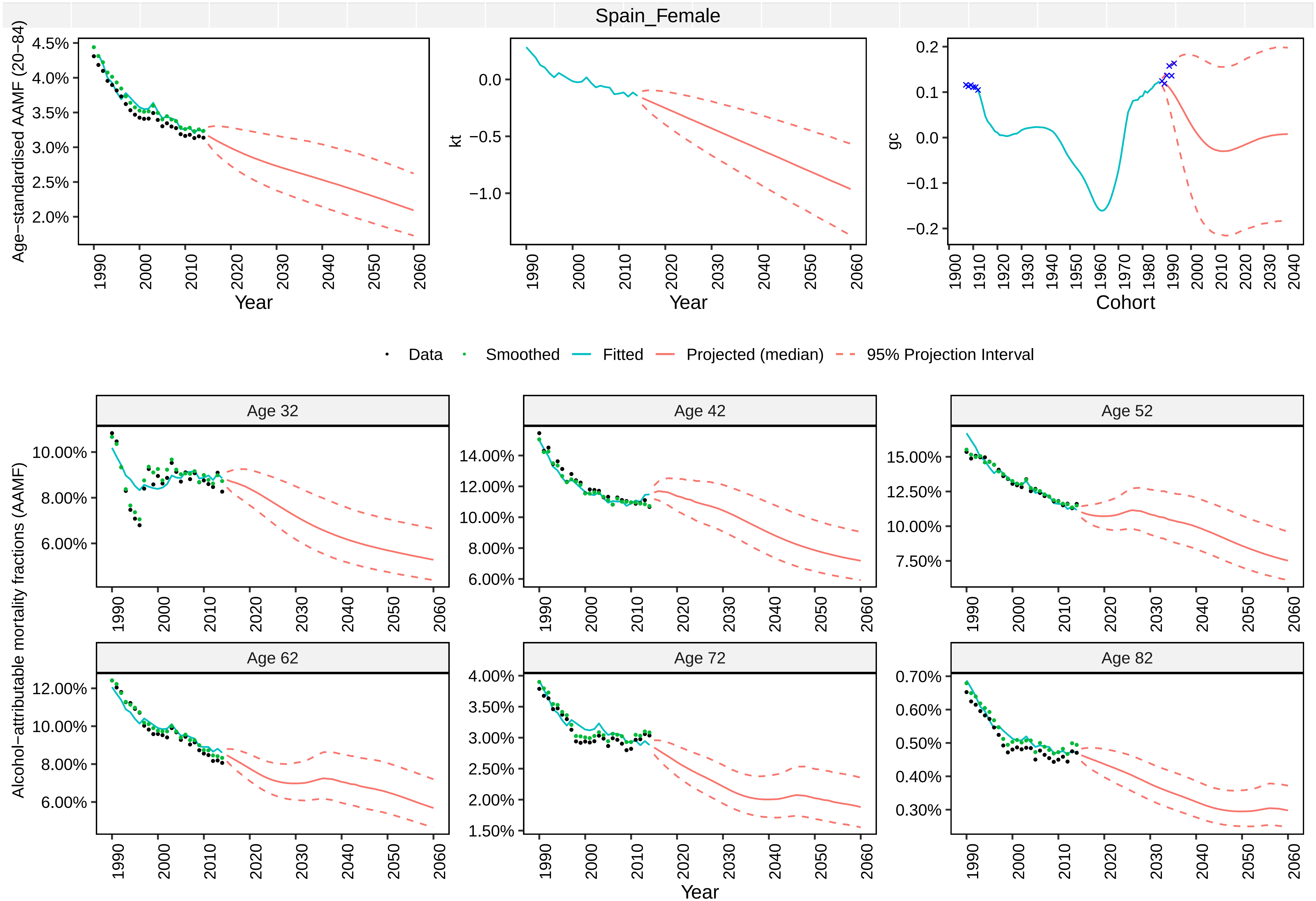
Portugal_Female
Age−standardised AAMF (20−84)
5.0%
4.0%
3.0%
2.0%
Year
kt
0.0
−0.5
−1.0
−1.5
gc
0.2
0.1
0.0
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)



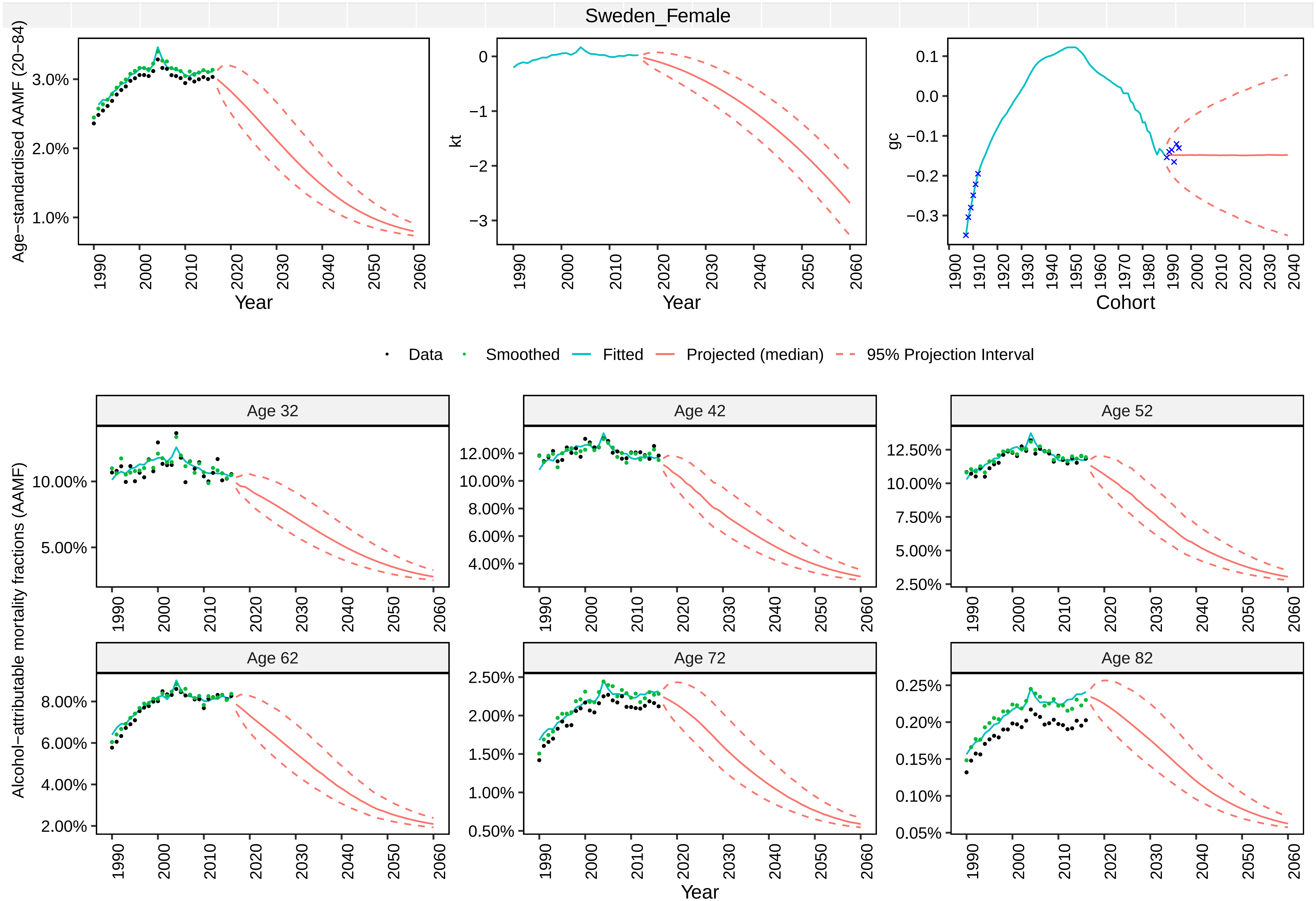
Russia_Female
Age−standardised AAMF (20−84)
6.0%
4.0%
2.0%
Year
kt
0
−5
−10
−15
gc
1
0
−1
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
30.00%
25.00%
20.00%
15.00%
10.00%
12.50%
7.50%
5.00%
2.50%
0.00%
3.00%
2.00%
1.00%
0.20%
0.10%
1990
2000
2010
2020
2030
2040
2050
2060
1900
1910
1920
1930
1940
1950
1960
1970
1980
Year



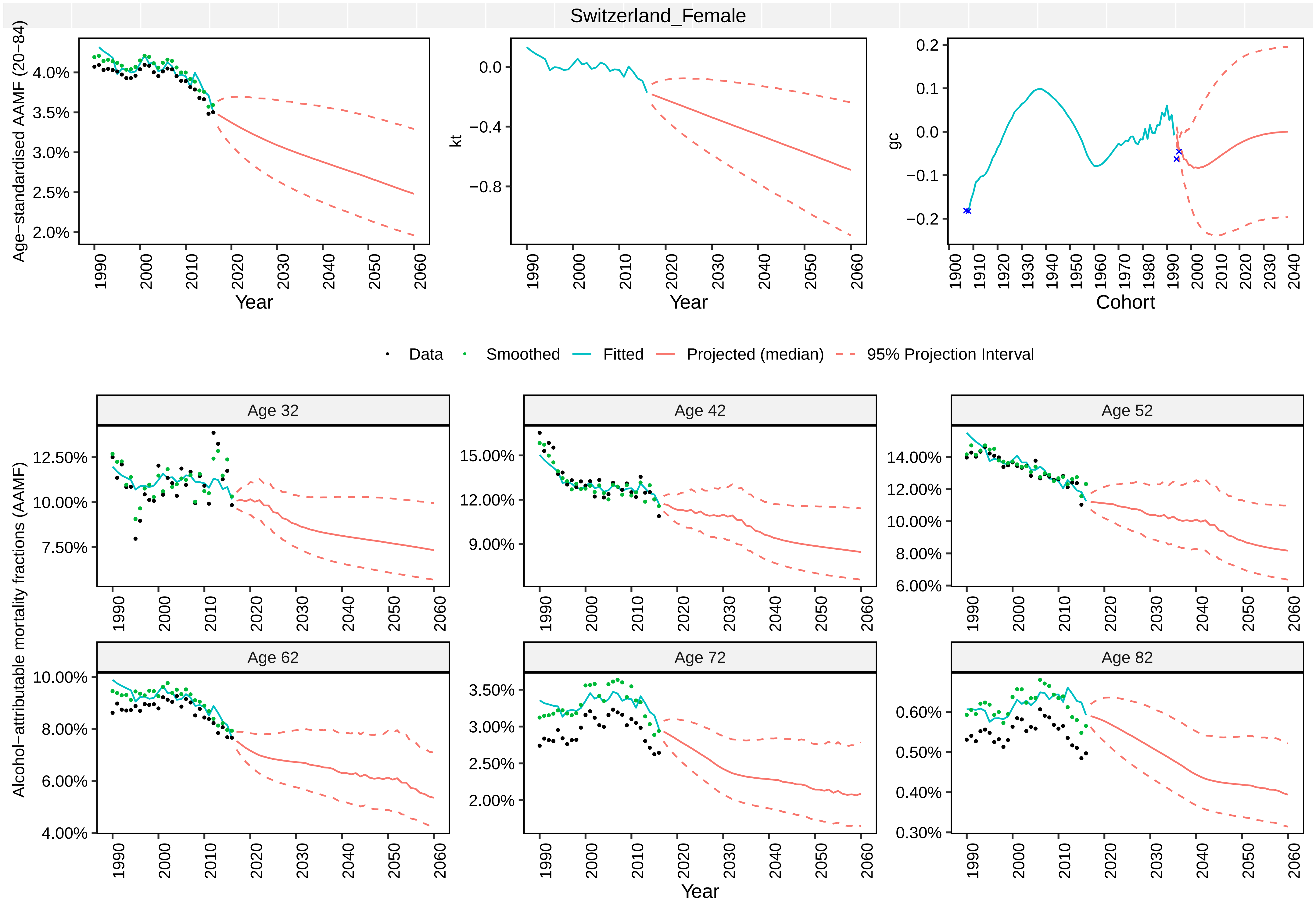
Slovenia_Female
Age−standardised AAMF (20−84)
3.0%
2.5%
2.0%
1.5%
1.0%
Year
kt
0.0
−0.5
−1.0
−1.5
−2.0
Year
gc
0
−1
−2
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Alcohol−attributable mortality fractions (AAMF)
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
12.50%
10.00%
7.50%
5.00%
2.50%
7.00%
6.00%
4.00%
3.00%
2.00%
1.50%
0.50%
0.40%
0.30%
0.20%
1990
2000
2010
2020
2030
2040
2050
2060
1900
1910
1920
1930
1940
1950
1960
1970
1980
Year



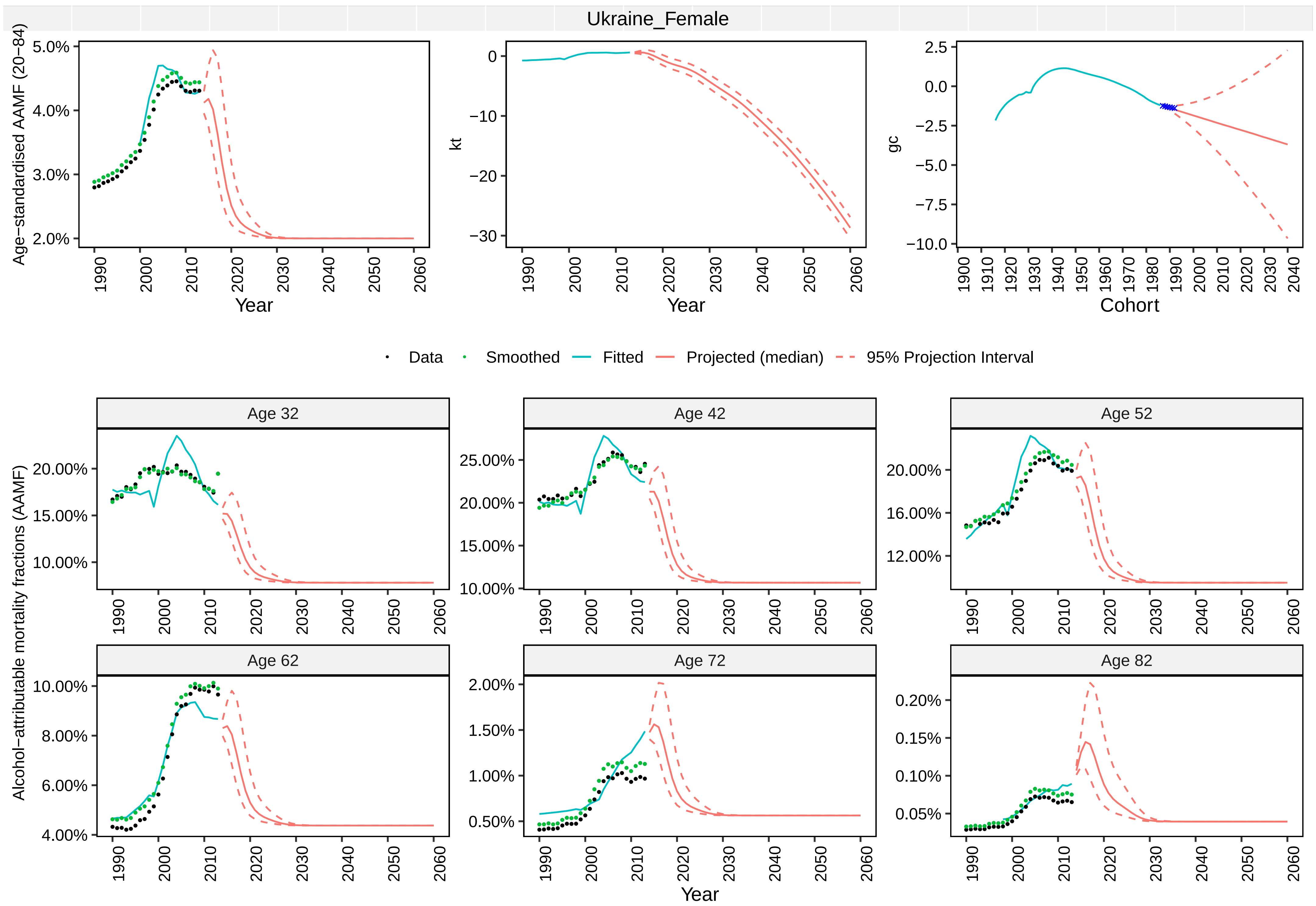
Spain_Female
Age−standardised AAMF (20−84)
Year
kt
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



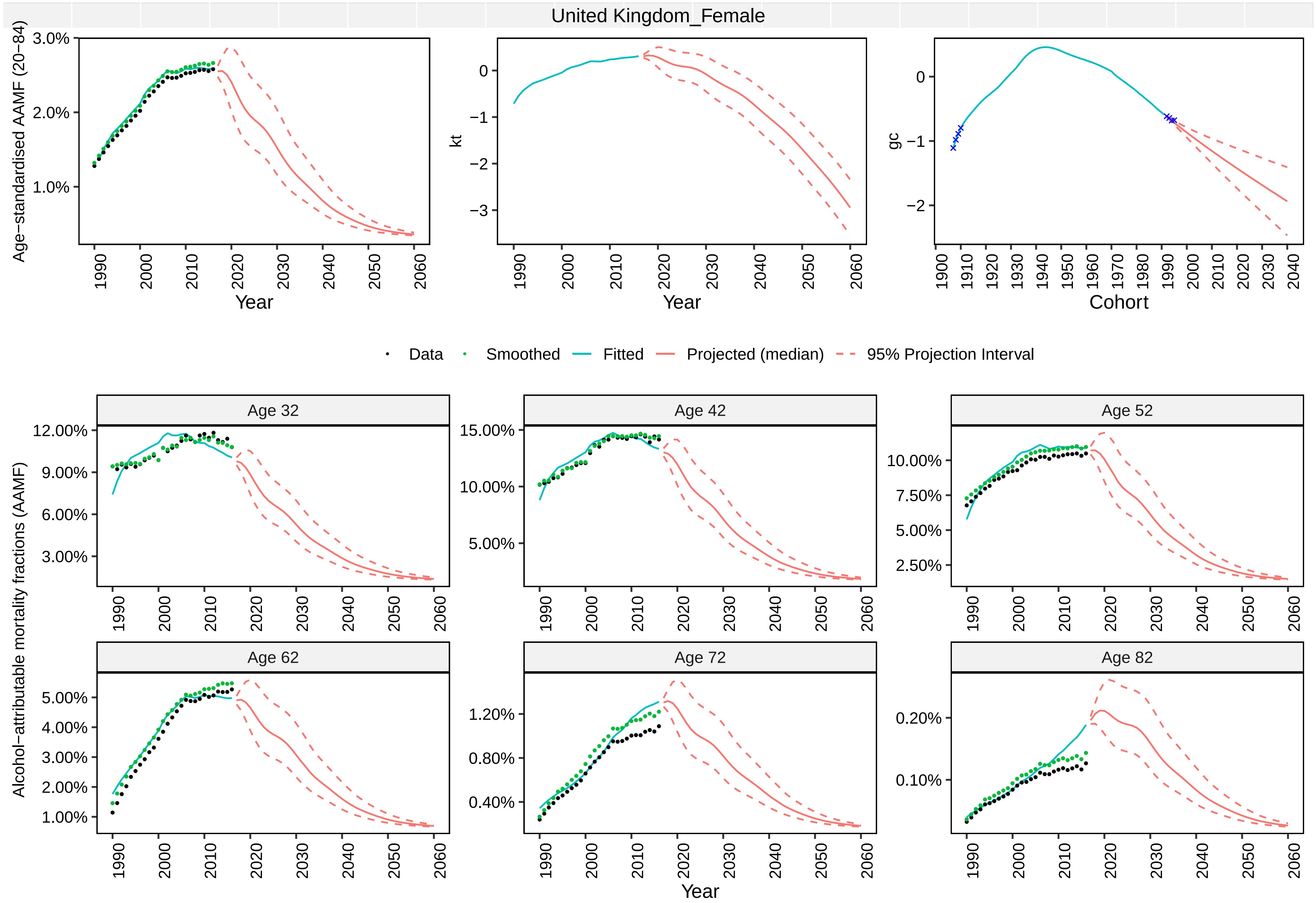
Sweden_Female
Age−standardised AAMF (20−84)
3.0%
2.0%
1.0%
Year
kt
0
−1
−2
−3
Year
gc
0.1
0.0
−0.1
−0.2
−0.3
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



Switzerland_Female
Age−standardised AAMF (20−84)
4.0%
3.5%
3.0%
2.5%
2.0%
Year
kt
0.0
−0.4
−0.8
gc
0.2
0.1
0.0
−0.1
−0.2
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
12.50%
10.00%
7.50%
15.00%
12.00%
9.00%
14.00%
12.00%
10.00%
8.00%
6.00%
4.00%
3.50%
3.00%
2.50%
2.00%
0.60%
0.50%
0.40%
0.30%
Year



Ukraine_Female
Age−standardised AAMF (20−84)
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year



United Kingdom_Female
Age−standardised AAMF (20−84)
3.0%
2.0%
1.0%
Year
kt
Year
gc
Cohort
Data
Smoothed
Fitted
Projected (median)
95% Projection Interval
Age 32
Age 42
Age 52
Age 62
Age 72
Age 82
Alcohol−attributable mortality fractions (AAMF)
Year

We project (age-specific) alcohol-attributable mortality up to 2060 in 26 European countries by carefully assessing past trends and applying advanced projecting techniques. We used estimated sex and age-specific alcohol-attributable mortality fractions (AAMF) among the national populations aged 20-84, for 1990 up to 2016, from the Global Burden of Disease Study, which we adjusted at older ages. We applied age-period-cohort modelling and projection, and avoided unrealistic future crossovers and differences in age-standardised AAMF between sexes and country groups, by implementing different lower bounds and by enabling that current (stagnating) increases are turned into declines. We find that in 2016, age-standardised AAMF were substantially higher among men (10.1%) than women (3.3%), and were much higher in Eastern Europe (14.3%) than in Western Europe (8.2%) among men. From 1990 to 2016, age-standardised AAMF mostly increased in Eastern and North-western Europe, and then declined or stagnated; whereas in South-western Europe, AAMF mostly declined, albeit with decelerations, particularly among men. We project that in the future, AAMF levels will decline in all countries, and will converge across countries, but that for men, levels will be higher in Eastern and South-western Europe than in North-western Europe. For 2060, projected AAMF are, on average, 5.1% among men and 1.4% among women.

In sum, the share of mortality due to alcohol is projected to eventually decline in all 26 European countries, and to converge across countries and sexes. Particularly for Eastern and North-western European countries, achieving these projected declines will require strong, ongoing public health action.

NIDI is a research institute of the Royal Academy of Arts and Sciences (KNAW) and is affiliated with the University of Groningen.

KNAW

university of groningen