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An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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Abstract

Objectives: Explore age, period, birth cohort effects and effects across different genders and immigration groups on mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers and their projections.

Design, Setting, and Participants: Death registry data in Hong Kong between 1998 and 2021. The population data were stratified by age, sex, immigration status, and length of stay in Hong Kong. Immigration status was classified into three groups: locals born in Hong Kong, long-stay immigrants and short-stay immigrants.

Main Outcomes and Measures: Age-period-cohort analysis was used to examine age, period, and birth cohort effects for genders and immigration groups from 1998 to 2021. Bayesian age-period-cohort models were applied to predict the mortality rates from 2022 to 2030.

Results: Short-stay immigrants indicated relatively pronounced fluctuations in age, cohort and period effects for six types of cancers, as increasing trends of age effect occurred for both genders and all immigration groups. Monotone decreasing trends or plateau of forecasting occur for both genders and all immigration groups in cancers except for increasing trends for short-stay male immigrants with colon cancer and long-stay male immigrants with pancreatic cancer. Long-stay male immigrants with lung cancer would perform the most significant decline in predictive mean from 100.18 to 79.55 deaths/100,000 population, while the same immigration group with pancreatic cancer would indicate the most significant uptrend in each year of 17.87 deaths and 23.49 deaths/100,000 population in 2022 and 2030, respectively.

Conclusions Immigrants had more pronounced fluctuations and sharper slopes of age, cohort, and period effects than locals. Men will be at a higher risk of mortality from cancers than women in the future, except for prostate cancer. Long-stay immigrants for each type of cancer and gender will be at a higher mortality risk than locals.

Keywords: Age-period-cohort analysis, immigration, mortality, lung cancer, pancreatic cancer, colon cancer, liver cancer, prostate cancer, stomach cancer

Strengths and limitations of this study

- Complicated population distribution has resulted in intricate causes of cancers, while few studies have assessed the relationship between immigration status and cancer mortality. This study provides new evidence regarding the relationship between immigration status and cancer mortality.

- We could only depict trends and variations among different immigration and sex groups and insufficiently perform the estimates of the contributions of three effects or subgroups to mortality rates.

Introduction

Several migration waves from mainland China to Hong Kong have occurred over the past century. These migration waves included a large-scale migration inflow from 1945 to 1950 (the Chinese Civil War) and a few small-scale inflows in the 1950s, 1970s, and 1990s [1-3]. In 2016, immigrants from mainland China formed approximately 38% of the population of Hong Kong. These inflows have led to a growing interest in research on the disparity of health conditions between the locals and immigrants.

Cancer has been one of most common causes of death, as an estimated 19.3 million new cancer cases and 9.9 million new cancer-associated deaths occurred worldwide in 2020 [4]. In Hong Kong, lung cancer is one of the most common causes of cancer deaths [5, 6]. Previous studies suggested that the primary cause of lung cancer is cigarette smoking [7-11]. Genetic factors, asbestos, radon gas, second-hand smoke, and other forms of air pollution have been proven to influence the risk of lung cancer [12-18]. The overall daily smoking rate in mainland China was approximately 23.2% in 2018 [21], whereas the daily smoking rate in Hong Kong was only 10.2% in 2019 [22]. The leading causes of liver cancer include viral infection, drinking of alcohol and polluted water and food supplies which are also culprits for colon, stomach and pancreatic cancer [19]. Alcohol consumption per capita in Hong Kong has reached to 2.37 liters in 2021 [23], compared to 7.0 liters of per capita consumption of alcohol in mainland China in 2018 [24]. As approximately 99% of prostate cancer cases occur after age 50, factors of prostate cancer have been regarded as old age, race, family history and the diet of red meat consumption [20]. In addition to these risk factors, studies have suggested that cancer mortality rates vary depending on migrant status [25-28]. According to data from the Census and Statistics Department of Hong Kong, approximately 81% of immigrants in Hong Kong immigrated from China mainland, Macau, and Taiwan. Immigrants from mainland China account for a bulk of this population. Previous studies have shown that child immigrants in Hong Kong tend to suffer from a higher risk of wheezing disorders and cardiovascular diseases, and immigrant women have higher age-specific mortality rates of breast cancer than locally-born women in Hong Kong [29, 30]. However, to date, few studies have investigated the effect of length of stay in Hong Kong and birthplace on the risk of other types of cancer.

In this study, we compared the mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers between locally born residents in Hong Kong and immigrants from mainland China. Both populations are widely considered as ethnically homogeneous with similar cultures. Nevertheless, due to different early life experiences, immigrants are exposed to more various social economy and lifestyle than locals. Therefore, it's constructive to ascertain whether immigrants from mainland China have a different mortality pattern of cancers with locals to

verify the significance of migration status for this health outcome. As Age-period-cohort (APC) analysis plays a vital role in studying time-specific phenomena in epidemiology, in this study, we developed APC models specified by sex and migrant status to assess the effects of age, period, birth cohort, and of the length of stay in Hong Kong on the mortality risks of cancers. Additionally, we predicted the mortality rates for the locally born population and immigrants in Hong Kong for the next 9 years using a predictive model, taking into account age, period, and birth cohort effects as well.

Materials and methods

Data

We obtained the death registry data in Hong Kong between 1998 and 2021 from the Census and Statistics Department of Hong Kong, as the data in 2022 has not been available up to now. The population data were stratified by age, sex, immigration status, and length of stay in Hong Kong. We retrieved six types of cancer cases from the death registry data using ICD codes, such as ICD-9 code 162 and ICD-10 codes C34.0–C34.3, C348, and C349 for lung cancer. To assure comparability among registries, deaths from the age group of 35–85 years were selected, since cases younger than 35 and older than 85 were relatively trivial for lack of statistical interpretability [31]. Immigration status was classified into three groups: locals born in Hong Kong, immigrants who have lived in Hong Kong for >10 years before death defined as long-stay immigrants, and immigrants who have lived in Hong Kong for ≤10 years before death defined as short-stay immigrants. Notably, much focus was placed on immigrants from mainland China, because approximately 81% of immigrants in Hong Kong came from mainland China, Macau, and Taiwan based on the data from the Census and Statistics Department of Hong Kong. Moreover, few cases recorded from Macau and Taiwan are statistically insignificant in the analysis. Demographics and population projections from 2022 to 2030 were retrieved from the Census and Statistics Department of Hong Kong and estimated with cubic smoothing spline as the prerequisite of the predictive model. Codes for APC and BAPC analysis are available in the GitHub repository (https://github.com/kshz2164313/APC-population-projections-for-immigration-HK).

Patient and Public Involvement

No patient involved. Death registry data was obtained from Census and Statistics Department of Hong Kong.

Statistical analysis

We modeled cancer mortality rates in Hong Kong using APC analysis based on log-linear Poisson regression models. The model aimed to disentangle age, period, and cohort effects of

time-varying phenomena simultaneously [32, 33], given that

$$\log(E_{ij}) = \alpha_i + \beta_j + \gamma_k + \mu + \log(\theta_{ij}) \quad (1)$$

where E_{ij} denotes expected mortality; α_i, β_j, and γ_k denote age, period, and cohort effect, respectively, for $i = 1,...,\mathrm{I}$, $j = 1,...,J$, $k = 1,...,K$ with $k = I - i + j$. $\log(\theta_{ij})$ is the offset. We mainly focused on the contributions of sex and immigration status due to the non-identifiability problem that the effects of these three components are collinear with each other (denoted as period – age = cohort) [34]. The median dates of birth among cases were regarded as the reference cohort, while the second and penultimate period effects were constrained to the reference groups, as birth cohort effect and period effect were assessed with relative risks. For sex and immigration status, maximum likelihood framework was applied to estimate the relative risks and 95% confidence intervals (CIs) by age groups, calendar period, and birth cohort.

Several projection approaches for future cancer mortality have been developed, but a Bayesian age-period-cohort (BAPC) model built upon integrated nested Laplace approximations (INLA) [35] yields relatively higher coverage and better performance for all evaluated parameter combinations [36]. To prevent some sampling problems caused by Markov chain Monte Carlo (MCMC), this MCMC-free BAPC approach was applied to predict future cancer mortality within a fully Bayesian inference setting and provide outputs of interest simply, such as projected age-standardized and age-specific rates. Convergence checks are not necessary for this technique [35]. The projections of age-standardized cancer mortality rates for each sex and migrant status, taking into account age, period, and birth cohort effects, were performed based on the weights of population age groups from the WHO World Standard population [37], with 95% prediction intervals.

All analyses were performed via R version 4.2.1 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria, 2013, http://www.R-project.org/). The APC models were established using the Epi package, and the projections based on Bayesian APC models were performed with the BAPC package.

Results

Figure 1ab, eFigure 1-4ab and eFigure 5a in Supplement 1 illustrate the estimates of age (assessed by cancer mortality), period and cohort effects (assessed by relative risk) based on APC models among three migrant groups for men and women with six types of cancers, respectively. All the mortality rates for each gender and immigration status exhibit notable increasing trends with age. Compared to other immigration groups, age, cohort and period

effects of six types of cancer for immigrants who stayed in Hong Kong for ≤10 years revealed relatively more pronounced fluctuations and deviations from those effects in other immigration groups. Significant increasing trends of age effect occurred in all types of cancer, regardless of gender and immigration status. For example, compared to no significant effects of immigration status for women on mortality rates of lung cancer by age (Figure 1b), the higher age effect for men who have stayed in Hong Kong for >10 years occurred after the age of 50 years and the lower age effect of men who had short stays occurred before the age of 62 years (Figure 1a). In addition to compatible dynamics of period effect for locals and long-stay immigrants, similar birth cohort effects for locals and long-stay immigrants in lung, colon, liver and stomach cancers occurred before 1945, whereas significant differences of birth cohort effects between these two immigration groups occurred after 1960. Locals and long-stay immigrants in pancreatic and prostate cancer perform almost similar cohort effects all the time. Local men and women had sharper slopes of cohort effect of short stay after 1950 than other immigration groups. Short-stay immigrants who have stayed in Hong Kong for ≤10 years had more fluctuating period effects before 2020 than those for locals and long-stay immigrants. Lack of young cases, especially young short-stay immigrants, of prostate cancer leads to significant deviations and variances in age and cohort effects.

Figure 1c, eFigure 1-4c and eFigure 5b in Supplement 1 illustrates the age-standardized mortality rates of six types of cancer from 1998 to 2021 and their projections by sex and immigrant status from 2022 to 2030, taking into account age, period, and birth cohort effects. Means and standard deviations of predictive mortality rates are shown in Table 1, Table 2 and eTable 1-4 in Supplement 1. Monotone decreasing trends or plateau of forecasting occur for both genders and all immigration groups in cancers except for increasing trends for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for > 10 years with pancreatic cancer. Except for prostate cancer, men will be at higher risk of mortality rates of cancers than women in the future. Given the future developing trends of other groups, the group of immigrant men who have stayed in Hong Kong for >10 years with lung, liver, pancreatic, prostate and colon cancer will have relatively higher mortality rates in each year compared with other immigration groups and pronounced decline in predictive mean. Compared with other cancers and immigration groups, male immigrants who have stayed in Hong Kong for >10 years with lung cancer would perform the most significant decline in predictive mean from 100.18 to 79.55 deaths per 100,000 population (average 2.92 deaths/100,000 per annum) (Table 1), while the same immigration group with pancreatic cancer would indicate the most significant uptrend in each year of 17.87 deaths and 23.49 deaths per 100,000 population in 2022 and 2030, respectively (average 0.62 deaths/100,000 per annum) (Table 2).

Discussion

Early detection of cancer is positive and instructive for increasing chances of cure. Nevertheless, the high mortality rate of cancer results from late diagnosis among most patients after progression to more advanced or severe stages. Individuals at high risk of cancer, such as smokers, alcoholics or those who are frequently exposed to susceptible circumstances, should be screened for early detections to increase opportunities for cure [38]. Therefore, the differences in mortality rates among immigration groups are synonymous with detection means, therapies, and social history in disparate periods and areas.

Age effects for both genders and all immigrant groups revealed pronounced increasing trends on all cancer mortality rates. The group of long-stay immigrants had a higher risk of death from lung, colon and liver cancers than the other two immigration groups after the age of 60 years. Short-stay male immigrants were less likely to die from lung cancer before the age of 65 years. The contrast in age effects among the immigration groups was partially consistent with studies [25, 39] that highlighted the age effects for locals and immigrants on breast cancer mortality in Hong Kong and lung cancer incidence in Sweden, as they both showed similar trends and magnitudes between locals and immigrants before the age of 60 years. They are also compatible with the results in [40] that diagnosis of liver cancer is the most frequent among populations at 55 to 65 years old. According to these trends, young individuals, especially new young immigrant men, who have benefited from all-rounded development in mainland China and Hong Kong, are more likely to seek early detection and be treated for cancers using more advanced treatments [41]. Differences in birth cohort effects among immigrant groups partially comply with the interpretation above.

We observed significant trends of cohort effects among locals and immigrants. These findings are partially consistent but subtly different from previous findings, regarding the effect of immigration status on cancers. Zhao et al. [25] described multiple peaks of cohort effects on breast cancer mortality between locals and immigrants in Hong Kong, as well as a significant decline of cohort effects after 1950. In contrast, Sung et al. [42] investigated the difference in breast cancer incidence between Chinese Americans and non-Hispanic whites in the U.S. and emphasized that Chinese Americans were at lower risk of breast cancer than non-Hispanic whites born in the same year. Here, we interpret the cohort-driven trends resulting from the intricacy of social history and lifestyle. Compared to a relatively stable social development in Hong Kong, representing downward trends of relative risks for locals, wars and social instability in mainland China resulted in several immigration waves from mainland China to Hong Kong before 1950. Additionally, remarkable increasing trends were recorded for new

immigrants after 1950, which corresponded to the economic downturn after wars and famine between 1959 and 1961 during their youth [43]. The increasing trends for new immigrants and similar trends for locals and long-stay immigrants were consistent with the finding that nutrient deficiency contributes to higher risk of severe mortality rates of cancers [44]. Furthermore, we speculate that these trends, especially those for locals and long-stay immigrants, are most likely attributed to social development and personal behaviors, such as daily habits, occupational history, different diagnoses and treatments, and domestic environmental exposures. It's notable that short-stay immigrants suffered from lower risk of death from colon cancer for all ages (eFigure 2ab in Supplement 1). As locals and immigrants in Hong Kong transitioned to a more westernized lifestyles, higher consumption of meat was associated with a higher risk of these types of cancer, whereas consumptions of vegetables had a strong protective effect against pancreatic cancer, and moderate consumption of coffee appeared to be beneficial against lung cancer [45,46]. Further studies on potential risk factors are required.

Short-stay immigrants had more fluctuating and non-stationary but inconspicuous period effects before 2021 than locals and long-stay immigrants. Cumulatively, an arch pattern and fluctuating curve depicting period effects externally resulted in an arch pattern of age-standardized mortality rates for short-stay immigrant women and irregular rates for short-stay immigrant men before 2021. The external performance of different period effects on mortality rates could be most likely attributed to the higher effect of different lifestyles and social development on new immigrants than on long-stay immigrants and locals in Hong Kong. With respect to the age-standardized mortality rates and projections, consistent with previous findings [47,48], we predict that the mortality rates of cancer in Hong Kong after 2021 will continue to decline or remain relatively stable, consistent with the trends before 2020, except for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer. Men will be at higher risk of mortality rates of cancer than women, regardless of immigration status. They are also compatible with the results in [4] that males suffer from higher risk of these types of cancer except for prostate cancer than females. Furthermore, new immigrant women will be at lower risk than local women, even though long-stay immigrants will suffer from higher mortality rates than locals in the future. Potential interpretations could be consistent with those for birth cohort effects, as age and period effect are considered as confounders of cohort effect.

In the past few decades, spurred by an increasing burden of high incidence and mortality rates of cancer, several studies focused on the inherent identification dilemma of three effects in the APC model. Further, complicated population distribution and immigration status in Hong

Kong, one of the areas with the highest population density and migration frequency in the world, have intricate causes and inherent dynamics of cancer and other diseases. To our knowledge, few studies have assessed the relationship between immigration status and cancer mortality. Therefore, this study is original to examine the effect of the length of stay in Hong Kong and origins of previous residence on cancer deaths, which is instructive for further immigration policy making and targeted strategies of disease detection and intervention. However, this study had several limitations. Given the non-identifiability problem in age-period-cohort models, we could only depict trends and variations among different immigration and sex groups, as illustrated in figures, and insufficiently perform the estimates of the contributions of three effects or subgroups to mortality rates. Furthermore, we adopted cubic smoothing spline to estimate populations of immigrants and locals due to the large proportion of unspecified immigration status from official demographic projections.

Conclusion

We conclude that immigrants, especially short-stay immigrants, had more pronounced fluctuations and sharper slopes of age, cohort, and period effects than locals. Men will be at a higher risk of mortality rates of six types of cancer than women in the future. Male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer would perform significant uptrend in the future, while other immigration groups for each type of cancer would continue to decline or remain relatively stable. The predictive means of long-stay immigrants for each type of cancer would be greater than locals.

Declaration

Ethical approval and consent to participate

Ethical approval and consent to participate are not applicable. This study does not involve human participants. Data was obtained from the Census and Statistics Department of Hong Kong.

Consent for publication

Not applicable.

Availability of data and materials

Data of population in Hong Kong was retrieved from Census and Statistics Department. Codes for APC and BAPC analysis are available in the GitHub repository https://github.com/kshz2164313/APC-population-projections-for-immigration-HK

Author contributions

Yanji Zhao: Methodology, Formal analysis, Data Curation, Writing - Original Draft, Visualization
Zian Zhuang: Methodology, Formal analysis, Data Curation, Writing - Review & Editing
Lin Yang: Validation, Writing - Review & Editing
Daihai He: Conceptualization, Writing - Review & Editing, Supervision

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Conflict of interest

None declared.

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Figure 1. Parameter estimates of age, period and cohort effects based on an age-period-cohort model of males' (a) and females' (b) lung cancer mortality rates and projections from 2022 to 2030 (c) by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands. Observations in (c) are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of blue represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Predictive mean of age-standardized morality rates of lung cancer per 100,000 population						
Year	Female immigrants >10 (SD)	Female immigrants ≤10 (SD)	Female locals (SD)	Male immigrants >10 (SD)	Male immigrants ≤10 (SD)	Male locals (SD)
2022	41.33(1.86)	22.21(4.67)	30.21(3.54)	100.18(4.18)	79.89(10.40)	52.26(4.85)
2023	40.58(2.26)	20.55(5.37)	30.63(4.77)	97.17(5.33)	79.81(11.82)	50.82(5.38)
2024	39.86(2.74)	19.01(6.10)	31.05(6.38)	94.33(6.71)	79.72(13.42)	49.56(6.12)
2025	39.18(3.28)	17.57(6.80)	31.47(8.29)	91.69(8.24)	79.62(15.18)	48.17(6.96)
2026	38.52(3.85)	16.23(7.45)	31.89(10.46)	89.14(9.83)	79.49(17.08)	46.64(7.83)
2027	37.88(4.46)	15.00(8.04)	32.31(12.86)	86.65(11.46)	79.32(19.09)	45.12(8.75)
2028	37.26(5.09)	13.85(8.56)	32.73(15.48)	84.18(13.10)	79.08(21.17)	43.82(9.75)
2029	36.64(5.73)	12.79(9.01)	33.14(18.30)	81.80(14.73)	78.77(23.32)	42.66(10.79)
2030	36.04(6.39)	11.80(9.39)	33.55(21.32)	79.55(16.37)	78.40(25.52)	41.43(11.79)

Table 1. Predictive means and standard deviations of age-standardized morality rates of lung cancer per 100,000 population for each gender and immigrant status from 2022 to 2030.

Predictive mean of age-standardized morality rates of pancreatic cancer per 100,000 population						
Year	Female immigrants >10 (SD)	Female immigrants ≤10 (SD)	Female locals (SD)	Male immigrants >10 (SD)	Male immigrants ≤10 (SD)	Male locals (SD)
2022	11.11(0.74)	5.437(1.55)	9.011(1.22)	17.87(1.18)	7.874(2.37)	12.28(1.48)
2023	11.35(0.90)	5.436(1.69)	9.150(1.33)	18.48(1.49)	7.760(2.53)	12.48(1.64)
2024	11.61(1.09)	5.430(1.83)	9.289(1.47)	19.11(1.87)	7.639(2.70)	12.69(1.83)
2025	11.87(1.31)	5.420(1.99)	9.429(1.64)	19.77(2.31)	7.511(2.87)	12.89(2.06)
2026	12.14(1.56)	5.405(2.15)	9.569(1.83)	20.46(2.83)	7.376(3.05)	13.11(2.32)
2027	12.42(1.83)	5.386(2.31)	9.710(2.04)	21.18(3.41)	7.237(3.22)	13.32(2.63)
2028	12.70(2.14)	5.363(2.48)	9.851(2.28)	21.92(4.07)	7.094(3.40)	13.55(2.96)
2029	12.99(2.48)	5.337(2.66)	9.994(2.54)	22.69(4.79)	6.946(3.57)	13.78(3.33)
2030	13.29(2.84)	5.307(2.84)	10.13(2.82)	23.49(5.60)	6.796(3.75)	14.02(3.74)

Table 2. Predictive means and standard deviations of age-standardized morality rates of pancreatic cancer per 100,000 population for each gender and immigrant status from 2022 to 2030.

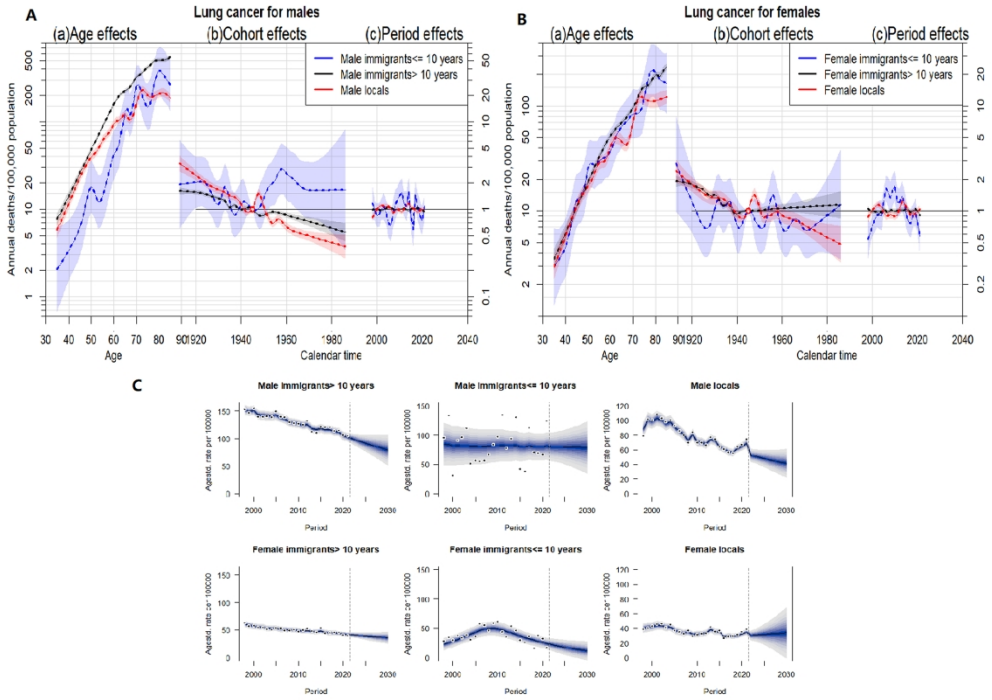

Figure 1. Parameter estimates of age, period and cohort effects based on an age-period-cohort model of males' (a) and females' (b) lung cancer mortality rates and projections from 2022 to 2030 (c) by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands. Observations in (c) are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of blue represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

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Predictive mean of age-standardized morality rates of colon cancer per 100,000 population						
Year	Female immigrants >10 (SD)	Female immigrants ≤10 (SD)	Female locals (SD)	Male immigrants >10 (SD)	Male immigrants ≤10 (SD)	Male locals (SD)
2022	18.95(1.12)	7.704(2.50)	13.46(1.59)	29.81(1.45)	16.77(3.76)	19.80(2.07)
2023	18.76(1.36)	7.248(2.81)	13.23(1.71)	29.65(1.79)	17.00(4.17)	19.38(2.21)
2024	18.58(1.65)	6.819(3.10)	13.00(1.86)	29.51(2.18)	17.22(4.64)	18.97(2.39)
2025	18.42(1.97)	6.415(3.37)	12.76(2.04)	29.39(2.62)	17.45(5.14)	18.57(2.61)
2026	18.26(2.33)	6.034(3.61)	12.53(2.24)	29.30(3.11)	17.66(5.68)	18.17(2.85)
2027	18.11(2.70)	5.674(3.82)	12.29(2.45)	29.21(3.63)	17.88(6.27)	17.79(3.11)
2028	17.98(3.10)	5.334(4.01)	12.05(2.68)	29.13(4.19)	18.09(6.89)	17.42(3.40)
2029	17.85(3.52)	5.013(4.17)	11.82(2.91)	29.05(4.77)	18.30(7.56)	17.06(3.69)
2030	17.72(3.96)	4.710(4.30)	11.58(3.16)	28.98(5.38)	18.50(8.25)	16.70(4.00)

eTable 1. Predictive means and standard deviations of age-standardized morality rates of colon cancer per 100,000 population for each gender and immigrant status from 2022 to 2030.

Predictive mean of age-standardized morality rates of liver cancer per 100,000 population						
Year	Female immigrants >10 (SD)	Female immigrants ≤10 (SD)	Female locals (SD)	Male immigrants >10 (SD)	Male immigrants ≤10 (SD)	Male locals (SD)
2022	10.67(0.71)	8.65(1.81)	6.36(0.87)	49.22(2.36)	39.02(6.48)	22.16(2.08)
2023	10.09(0.85)	8.38(1.94)	6.07(0.90)	47.76(2.93)	37.38(7.46)	21.01(2.21)
2024	9.53(1.00)	8.11(2.08)	5.79(0.93)	46.35(3.59)	35.79(8.51)	19.91(2.38)
2025	9.01(1.15)	7.84(2.21)	5.52(0.97)	44.99(4.30)	34.25(9.58)	18.85(2.58)
2026	8.49(1.30)	7.58(2.35)	5.26(1.01)	43.66(5.04)	32.76(10.6)	17.83(2.78)
2027	8.02(1.45)	7.32(2.49)	5.01(1.06)	42.36(5.80)	31.31(11.6)	16.85(2.99)
2028	7.56(1.58)	7.07(2.62)	4.76(1.10)	41.10(6.56)	29.91(12.6)	15.91(3.20)
2029	7.13(1.71)	6.82(2.75)	4.53(1.15)	39.88(7.32)	28.55(13.5)	15.02(3.40)
2030	6.73(1.83)	6.58(2.88)	4.30(1.19)	38.70(8.08)	27.25(14.3)	14.17(3.58)

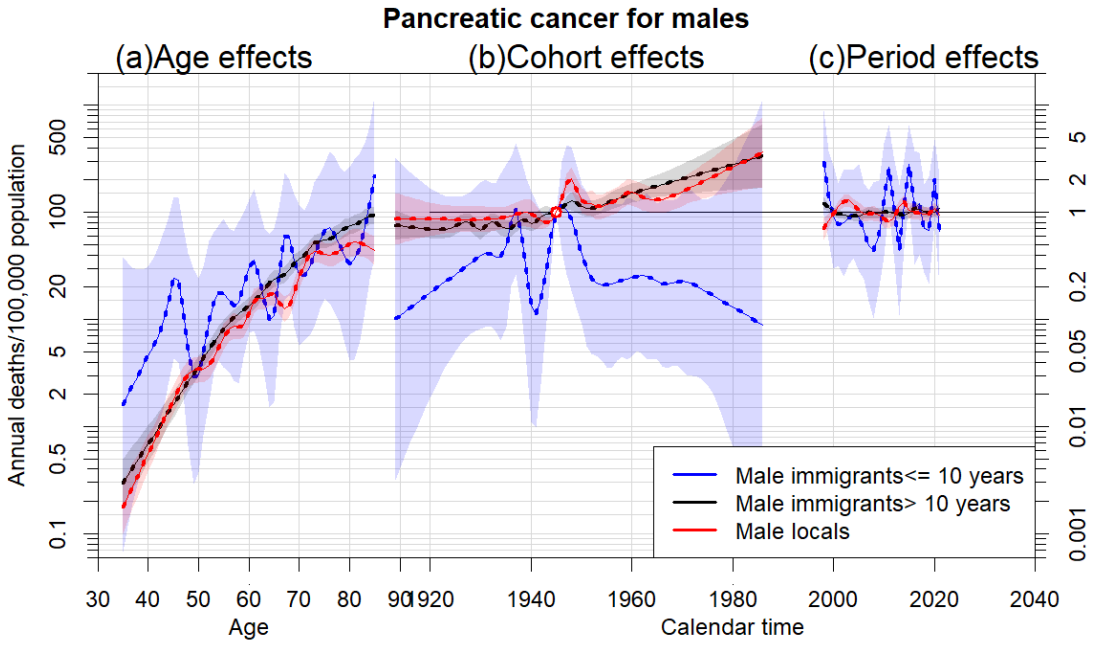
eTable 2. Predictive means and standard deviations of age-standardized morality rates of liver cancer per 100,000 population for each gender and immigrant status from 2022 to 2030.

Predictive mean of age-standardized morality rates of stomach cancer per 100,000 population						
Year	Female immigrants >10 (SD)	Female immigrants ≤10 (SD)	Female locals (SD)	Male immigrants >10 (SD)	Male immigrants ≤10 (SD)	Male locals (SD)
2022	7.94(0.62)	7.36(1.55)	4.89(0.51)	13.89(0.96)	15.19(3.38)	8.06(0.99)
2023	7.70(0.73)	7.32(1.69)	4.75(0.56)	13.33(1.20)	15.06(3.66)	7.73(1.02)
2024	7.47(0.86)	7.29(1.84)	4.61(0.62)	12.80(1.45)	14.92(3.97)	7.41(1.07)
2025	7.24(1.00)	7.28(2.01)	4.47(0.69)	12.30(1.72)	14.78(4.30)	7.09(1.12)
2026	7.03(1.14)	7.27(2.19)	4.33(0.76)	11.83(1.99)	14.64(4.65)	6.79(1.19)
2027	6.82(1.29)	7.27(2.39)	4.20(0.83)	11.38(2.25)	14.49(5.01)	6.50(1.25)
2028	6.62(1.43)	7.28(2.61)	4.07(0.91)	10.95(2.51)	14.34(5.39)	6.23(1.32)
2029	6.42(1.57)	7.30(2.84)	3.95(0.98)	10.53(2.76)	14.18(5.77)	5.96(1.39)
2030	6.24(1.71)	7.33(3.08)	3.82(1.06)	10.14(3.00)	14.03(6.16)	5.71(1.46)

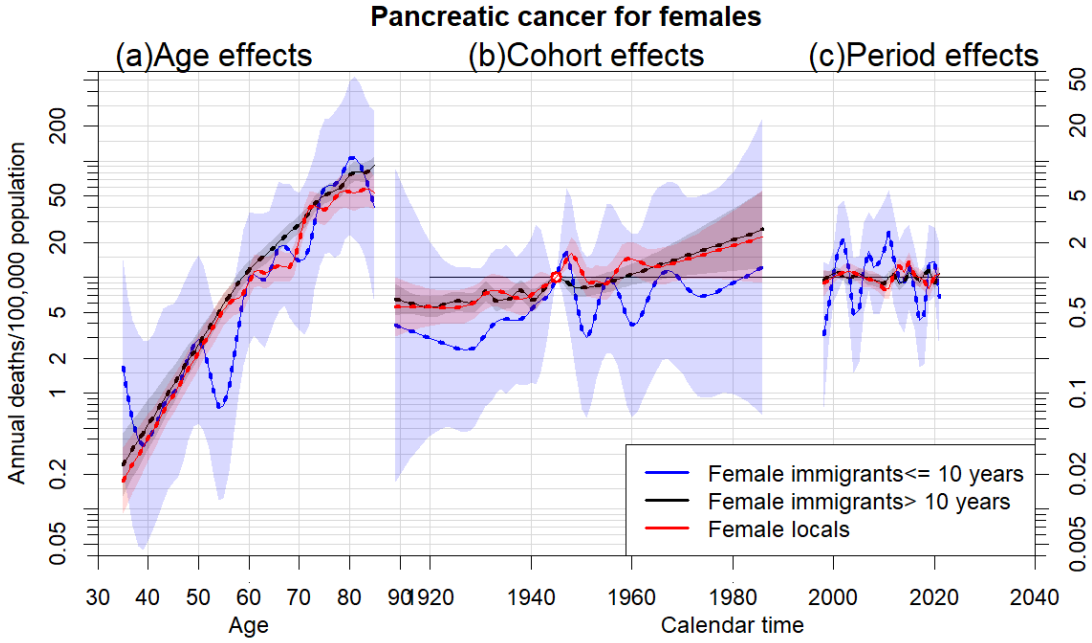
eTable 3. Predictive means and standard deviations of age-standardized morality rates of stomach cancer per 100,000 population for each gender and immigrant status from 2022 to 2030.

Predictive mean of age-standardized morality rates of prostate cancer per 100,000 population			
Year	Male immigrants >10 (SD)	Male immigrants ≤10 (SD)	Male locals (SD)
2022	14.58(0.79)	8.77(3.10)	9.65(1.56)
2023	14.57(0.95)	8.58(3.29)	9.67(1.65)
2024	14.55(1.14)	8.38(3.48)	9.69(1.76)
2025	14.53(1.36)	8.19(3.68)	9.71(1.90)
2026	14.51(1.60)	8.00(3.89)	9.74(2.05)
2027	14.48(1.86)	7.81(4.09)	9.78(2.23)
2028	14.45(2.13)	7.63(4.30)	9.81(2.43)
2029	14.41(2.42)	7.44(4.51)	9.85(2.64)
2030	14.37(2.71)	7.27(4.72)	9.89(2.87)

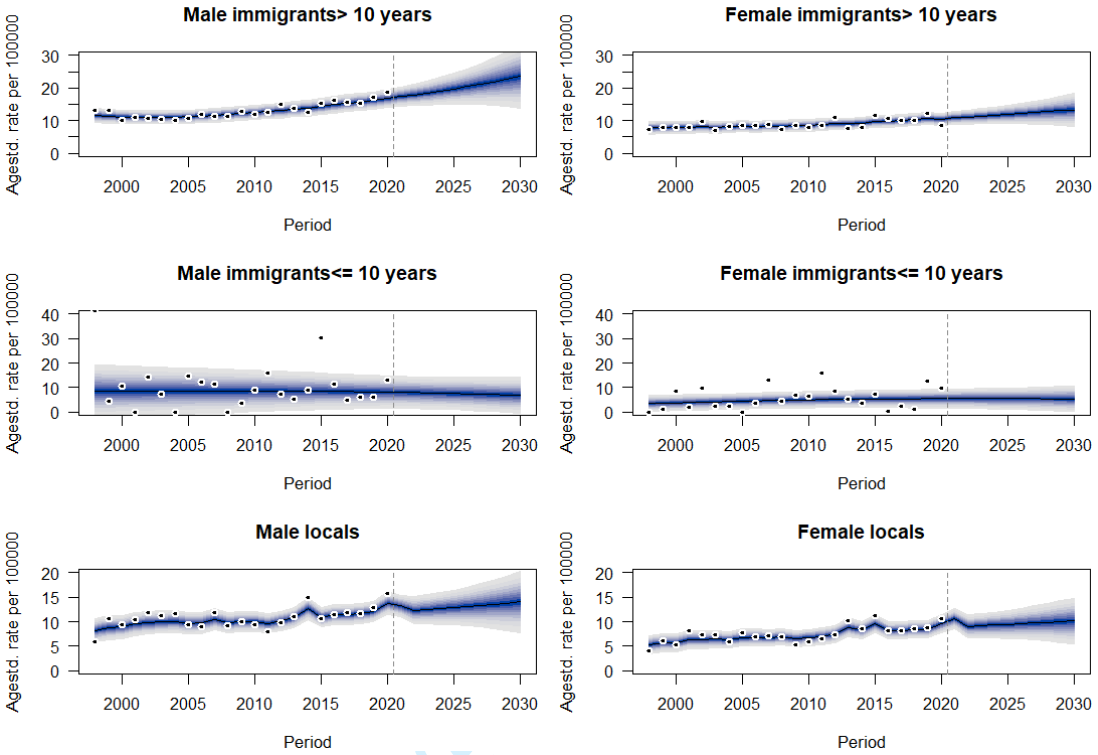
eTable 4. Predictive means and standard deviations of age-standardized morality rates of prostate cancer per 100,000 population for each gender and immigrant status from 2022 to 2030.



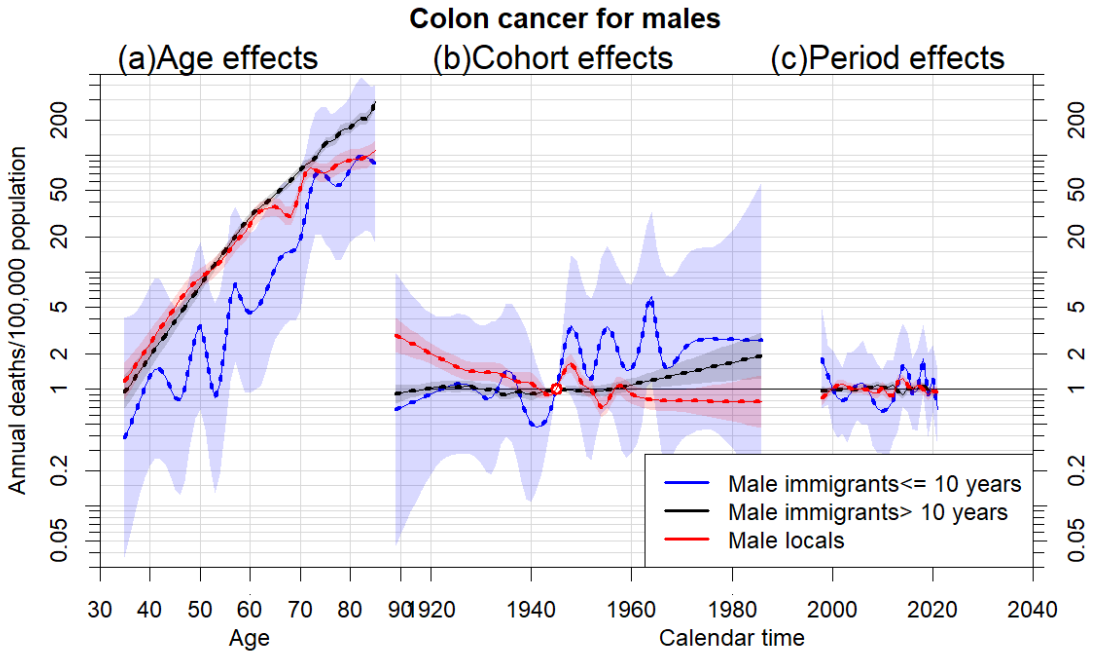
eFigure 1(a). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of male pancreatic cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



eFigure 1(b). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of female pancreatic cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



eFigure 1(c). Projections of pancreatic cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of blue represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 2(a). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of male colon cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

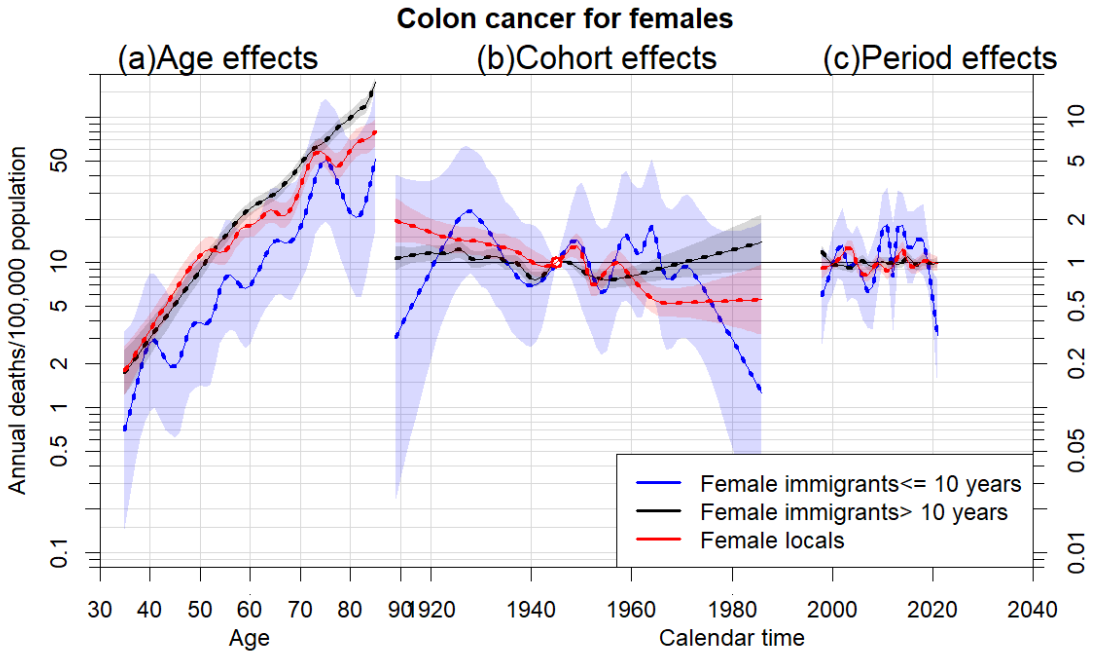
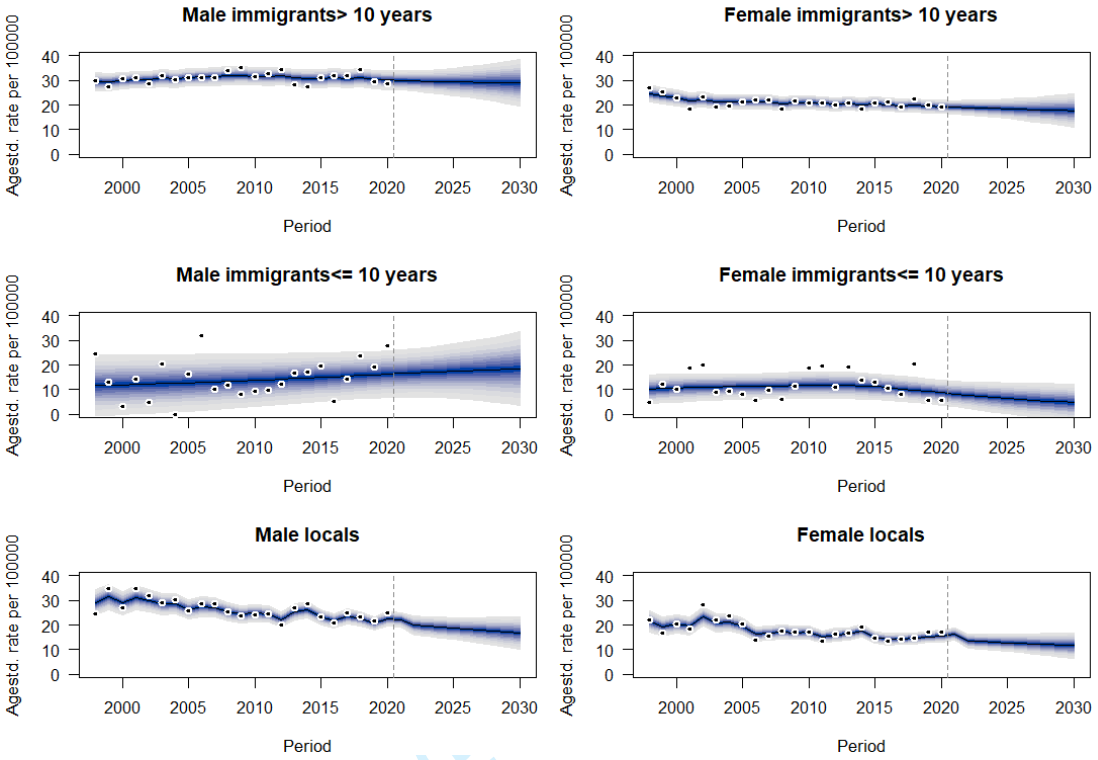
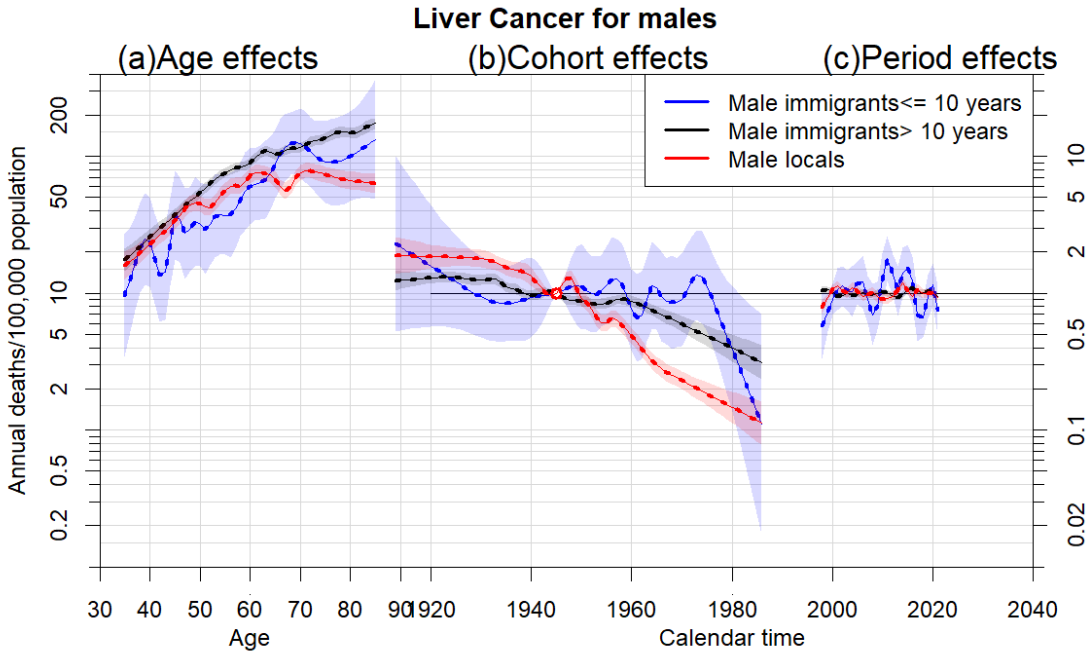


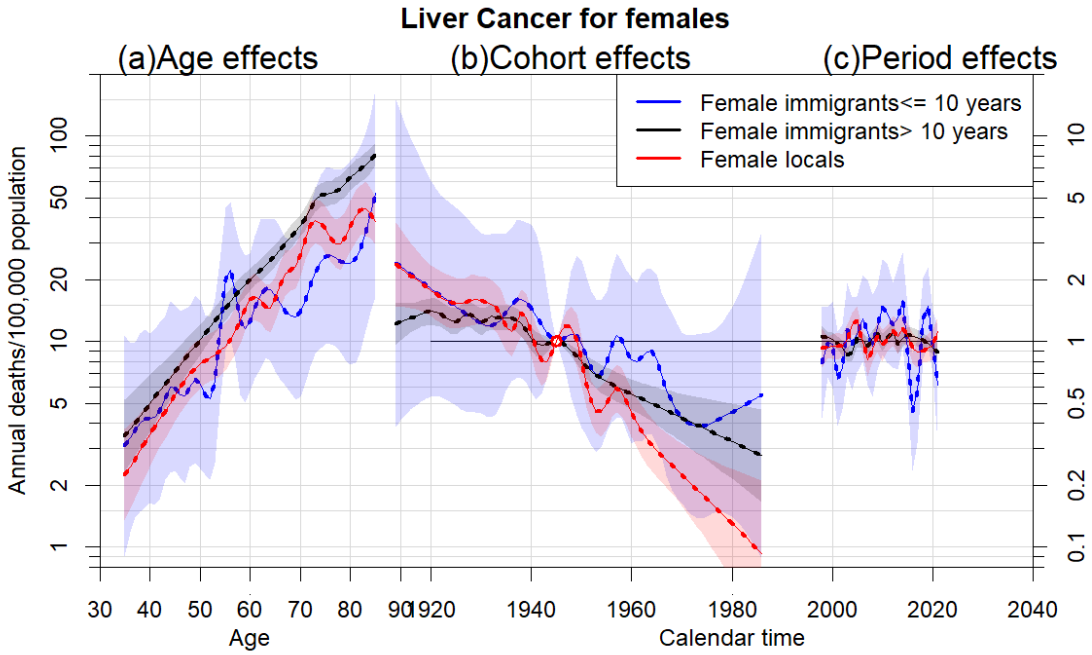
Figure 2(b). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of female colon cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



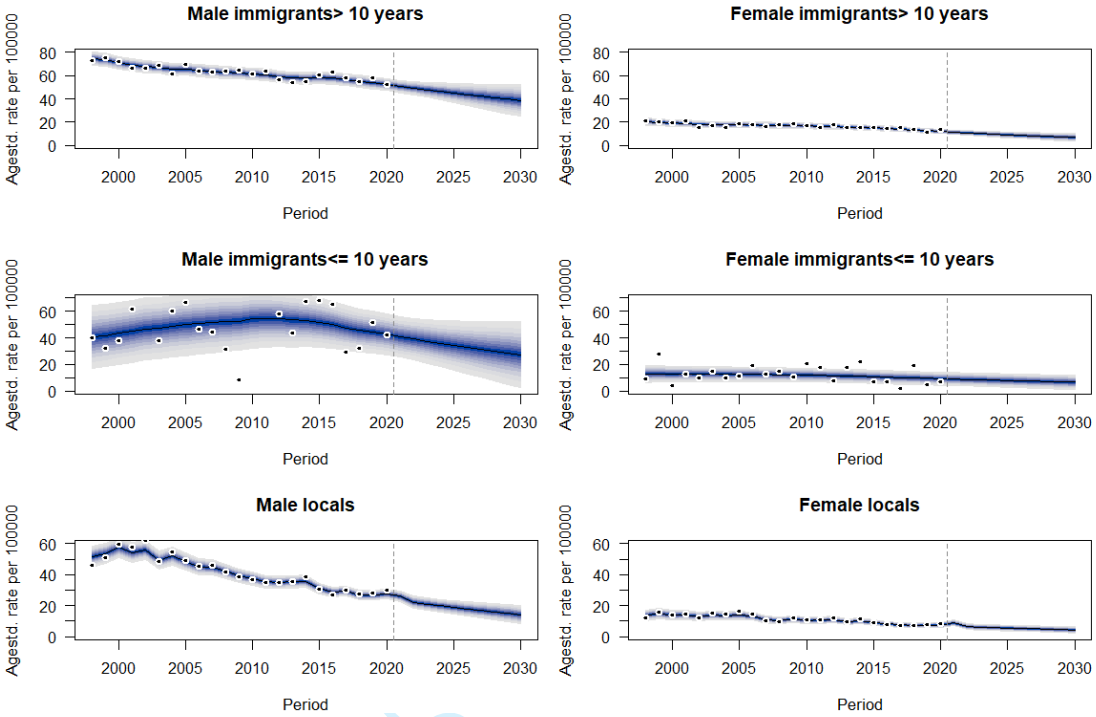
eFigure 2(c). Projections of colon cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of blue represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



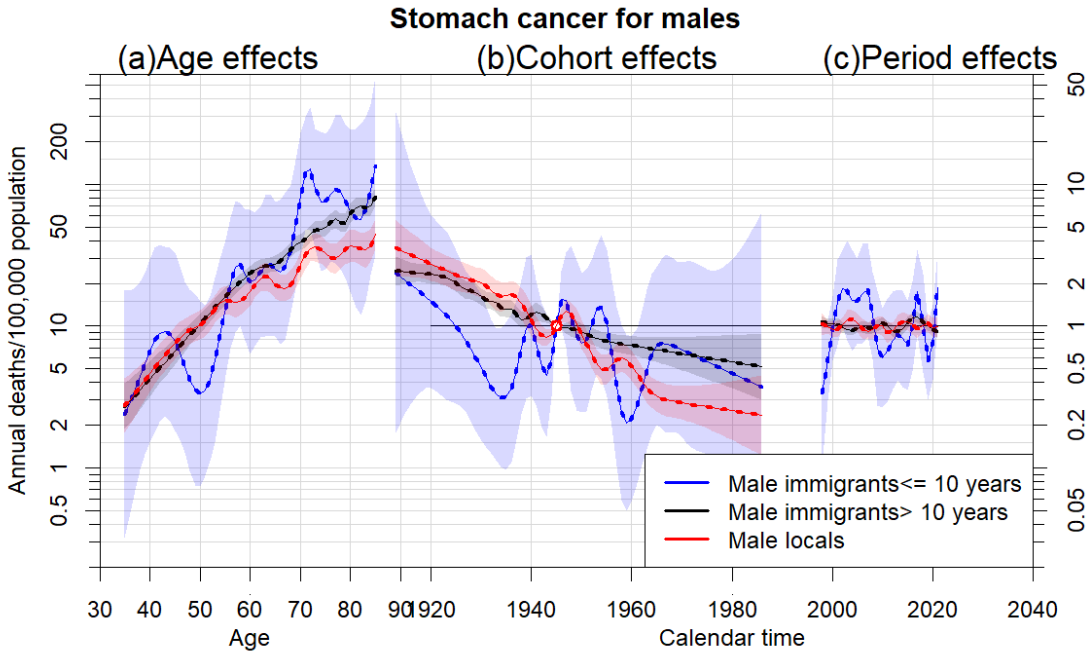
eFigure 3(a). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of male liver cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



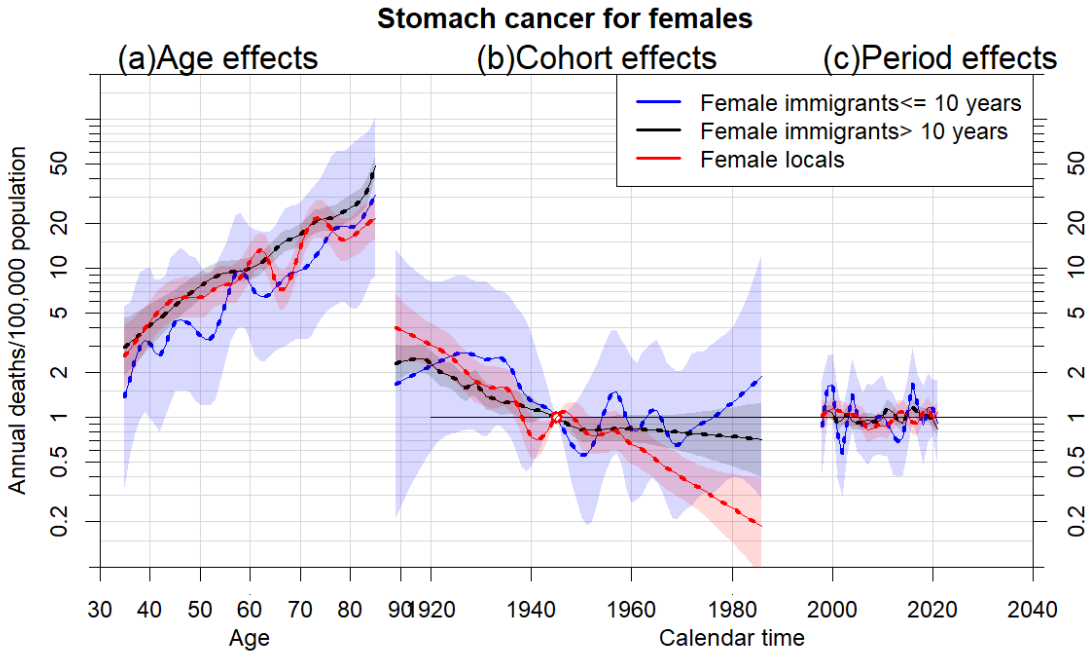
eFigure 3(b). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of female liver cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



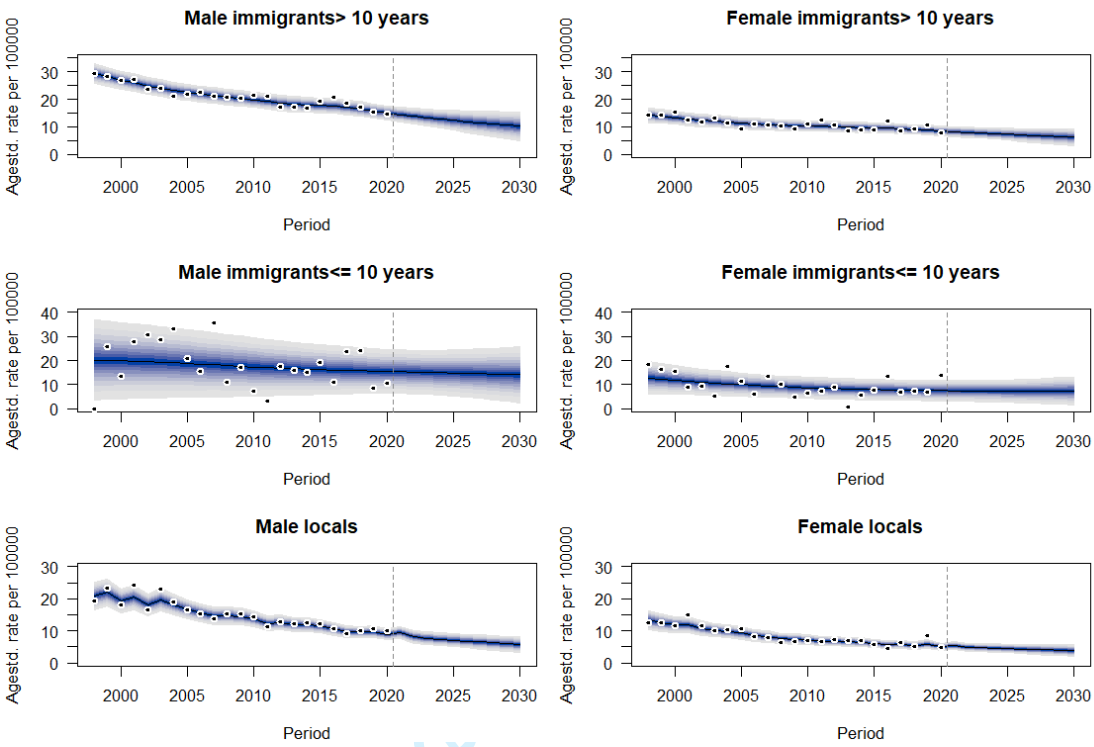
eFigure 3(c). Projections of liver cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of blue represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



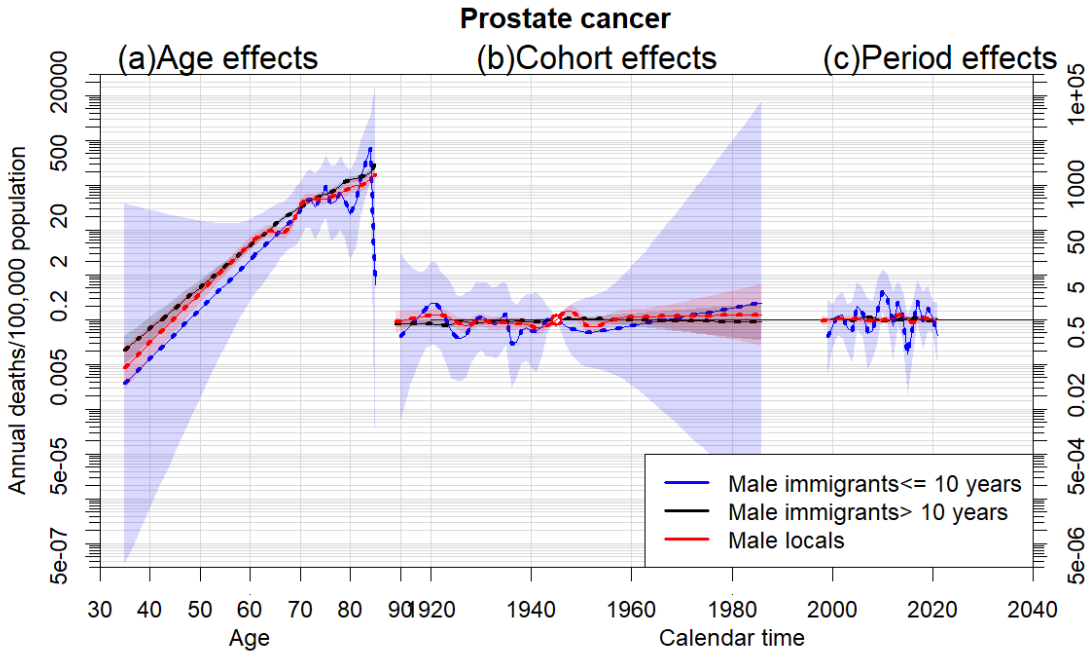
eFigure 4(a). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of male stomach cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



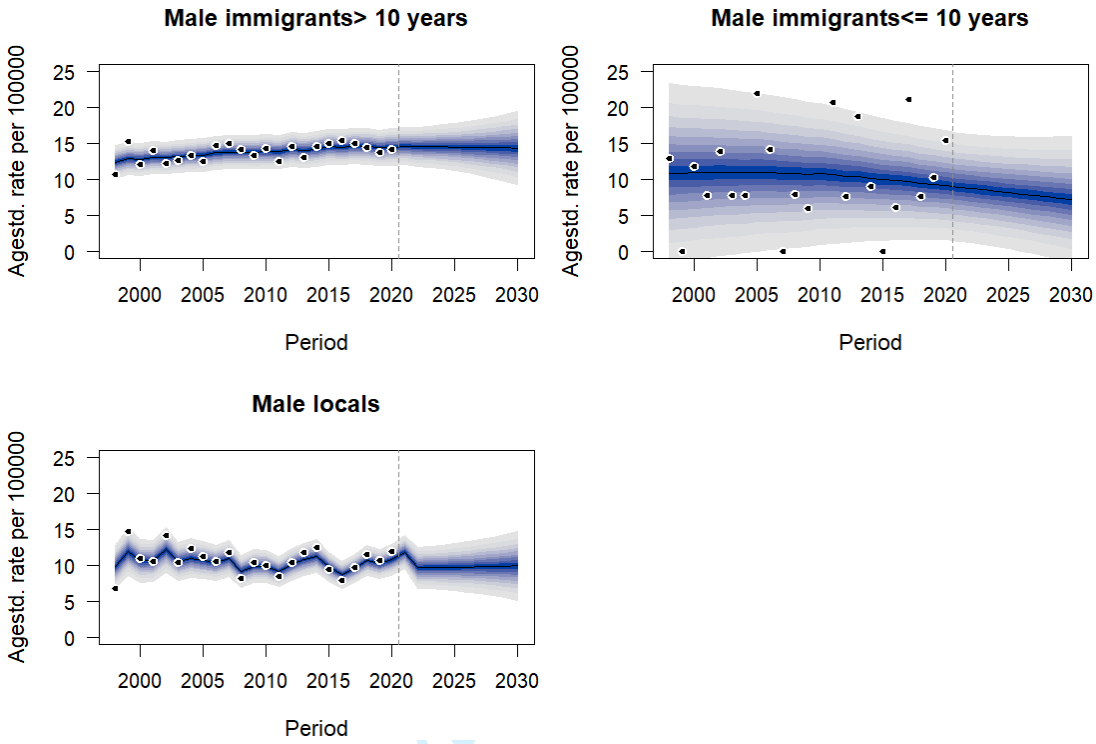
eFigure 4(b). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of female stomach cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



eFigure 4(c). Projections of stomach cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of blue represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 5(a). Parameter estimates of age (a), period (b) and cohort (c) effects based on an age-period-cohort model of male prostate cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



eFigure 5(b). Projections of prostate cancer mortality rates by immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of blue represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Reporting checklist for cohort study.

Based on the STROBE cohort guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cohortreporting guidelines, and cite them as:

von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.

		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	5
Setting	#5	Describe the setting, locations, and relevant dates, including periods	5

		of recruitment, exposure, follow-up, and data collection	
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up.	5
Eligibility criteria	#6b	For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5
Bias	#9	Describe any efforts to address potential sources of bias	5
Study size	#10	Explain how the study size was arrived at	5
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	5
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	
5			
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	5
Statistical methods	#12c	Explain how missing data were addressed	5
Statistical methods	#12d	If applicable, explain how loss to follow-up was addressed	n/a
Statistical methods	#12e	Describe any sensitivity analyses	
n/a			
Results			
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible,	n/a

		included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	5
Participants	#13c	Consider use of a flow diagram	
n/a			
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	5
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	
n/a			
Descriptive data	#14c	Summarise follow-up time (eg, average and total amount)	
n/a			
Outcome data	#15	Report numbers of outcome events or summary measures over time. Give information separately for exposed and unexposed groups if applicable.	
n/a			
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6
Main results	#16b	Report category boundaries when continuous variables were categorized	n/a
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
n/a			
Other analyses	#17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	7
Discussion			

Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	10
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

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An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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Abstract

Objectives: Complicated population distribution and immigration status in Hong Kong have brought out intricate causes of diseases. This study was aimed to explore age, period, birth cohort effects and effects across genders and immigration groups on mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers and their projections.

Design, Setting, and Participants: Death registry data in Hong Kong between 1998 and 2021, which were stratified by age, sex and immigration status. Immigration status was classified into three groups: locals born in Hong Kong, long-stay immigrants and short-stay immigrants.

Methods: Age-period-cohort analysis was used to examine age, period, and birth cohort effects for genders and immigration groups from 1998 to 2021. Bayesian age-period-cohort models were applied to predict the mortality rates from 2022 to 2030.

Results: Short-stay immigrants revealed pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Decreasing trends ($p<0.05$) or plateau ($p>0.05$) of forecasting mortality rates of cancers occur for all immigration groups, except for increasing trends for short-stay male immigrants with colon cancer (16.77 deaths to 18.50 deaths/100,000 $p<0.05$) and long-stay male immigrants with pancreatic cancer (17.87 deaths to 23.49 deaths/100,000 $p<0.05$). Men will be at a higher risk of mortality from cancers than women in the future (excluding prostate cancer). Immigrants for each type of cancer and gender will be at a higher mortality risk than locals.

Conclusions: Findings underscore the effect of gender and immigration status in Hong Kong on mortality risks of cancers that immigrants for each type of cancer and gender will be at a higher mortality risk than locals.

Keywords: Age-period-cohort analysis, immigration, mortality, lung cancer, pancreatic cancer, colon cancer, liver cancer, prostate cancer, stomach cancer

Strengths and limitations of this study

- This study provides new evidence regarding the relationship between immigration status and cancer mortality, given the effects of age, period, birth cohort and their predictions.
- The non-identifiability problem has not been interpreted in APC models
- The future perspective of cancer therapies and techniques have not been considered.

Introduction

Several migration waves from mainland China to Hong Kong have occurred over the past century. These migration waves included a large-scale migration inflow from 1945 to 1950 (the Chinese Civil War) and a few small-scale inflows in the 1950s, 1970s, and 1990s [1-3]. In 2016, immigrants from mainland China formed approximately 38% of the population of Hong Kong. These inflows have led to a growing interest in research on the disparity of health conditions between the locals and immigrants.

Cancer has been one of most common causes of death, as an estimated 19.3 million new cancer cases and 9.9 million new cancer-associated deaths occurred worldwide in 2020 [4]. In Hong Kong, lung cancer is one of the most common causes of cancer deaths [5, 6]. Previous studies suggested that the primary cause of lung cancer is cigarette smoking [7-11]. Genetic factors, asbestos, radon gas, second-hand smoke, and other forms of air pollution have been proven to influence the risk of lung cancer [12-18]. The overall daily smoking rate in mainland China was approximately 23.2% in 2018 [19], whereas the daily smoking rate in Hong Kong was only 10.2% in 2019 [20]. The leading causes of liver cancer include viral infection, drinking of alcohol and polluted water and food supplies which are also culprits for colon, stomach and pancreatic cancer [21]. Alcohol consumption per capita in Hong Kong has reached to 2.37 liters in 2021 [22], compared to 7.0 liters of per capita consumption of alcohol in mainland China in 2018 [23]. As approximately 99% of prostate cancer cases occur after age 50, factors of prostate cancer have been regarded as old age, race, family history and the diet of red meat consumption [24]. In addition to these risk factors, studies have suggested that cancer mortality rates vary depending on migrant status [25-28]. According to data from the Census and Statistics Department of Hong Kong, approximately 81% of immigrants in Hong Kong immigrated from China mainland, Macau, and Taiwan. Immigrants from mainland China account for a bulk of this population. Previous studies have shown that child immigrants in Hong Kong tend to suffer from a higher risk of wheezing disorders and cardiovascular diseases, and immigrant women have higher age-specific mortality rates of breast cancer than locally-born women in Hong Kong [29, 30]. However, to date, few studies have investigated the effect of length of stay in Hong Kong and birthplace on the risk of other types of cancer.

In this study, we compared the mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers between locally born residents in Hong Kong and immigrants from mainland China. Both populations are widely considered as ethnically homogeneous with similar cultures. Nevertheless, due to different early life experiences, immigrants are exposed to more various social economy and lifestyle than locals. Therefore, it's constructive to ascertain whether immigrants from mainland China have a different mortality pattern of cancers with locals to

verify the significance of migration status for this health outcome. As Age-period-cohort (APC) analysis plays a vital role in studying time-specific phenomena in epidemiology, in this study, we developed APC models specified by sex and migrant status to assess the effects of age, period, birth cohort, and of the length of stay in Hong Kong on the mortality risks of cancers. Additionally, we explore the projection of mortality rates for the locally born population and immigrants in Hong Kong who were younger or older than 60 using a predictive model, taking into account age, period, and birth cohort effects as well.

Methods

Data

We obtained the death registry data in Hong Kong between 1998 and 2021 from the Census and Statistics Department of Hong Kong, as the data in 2022 has not been available up to now. The data was extracted a routine census held by Hong Kong government as subjective errors caused by resampling can be neglected. The population data were stratified by age, sex, immigration status, and length of stay in Hong Kong. We retrieved six types of cancer cases from the death registry data using ICD codes, such as ICD-9 code 162 and ICD-10 codes C34.0–C34.3, C348, and C349 for lung cancer. To assure comparability among registries, deaths from the age group of 35–85 years were selected, since cases younger than 35 and older than 85 were relatively trivial for lack of statistical interpretability [31]. Immigration status was classified into three groups: locals born in Hong Kong, immigrants who have lived in Hong Kong for >10 years before death defined as long-stay immigrants, and immigrants who have lived in Hong Kong for ≤10 years before death defined as short-stay immigrants. Notably, much focus was placed on immigrants from mainland China, because approximately 81% of immigrants in Hong Kong came from mainland China, Macau, and Taiwan based on the data from the Census and Statistics Department of Hong Kong. Moreover, few cases recorded from Macau and Taiwan are statistically insignificant in the analysis. Demographics and population projections from 2022 to 2030 were retrieved from the Census and Statistics Department of Hong Kong and estimated with cubic smoothing spline as the prerequisite of the predictive model. Codes for APC and BAPC analysis are available in the GitHub repository (https://github.com/kshz2164313/APC-population-projections-for-immigration-HK).

Statistical analysis

We modeled cancer mortality rates in Hong Kong using APC analysis based on log-linear Poisson regression models. The model aimed to disentangle age, period, and cohort effects of time-varying phenomena simultaneously [32, 33], given that

$$\log(E_{ij}) = \alpha_i + \beta_j + \gamma_k + \mu + \log(\theta_{ij}) \quad (1)$$

where E_{ij} denotes expected mortality; α_i, β_j, and γ_k denote age, period, and cohort effect, respectively, for $i=1,...,\mathrm{I}$, $j=1,...,J$, $k=1,...,K$ with $k=I-i+j$. $\log(\theta_{ij})$ is the offset. We mainly focused on the contributions of sex and immigration status due to the non-identifiability problem that the effects of these three components are collinear with each other (denoted as period – age = cohort) [34]. Birth cohort effect and period effect were assessed with relative risks. The median date of birth among cases were regarded as the reference cohort. Since cases aged at 35–85 years between 1998 and 2021 were selected, the range of birth cohort from 1913 to 1986 covered observations and further projections until 2030. The second and penultimate period effects were constrained to the reference for period. For sex and immigration status, maximum likelihood framework was applied to estimate the relative risks and 95% confidence intervals (CIs) by age groups, calendar period, and birth cohort.

Several projection approaches for future cancer mortality have been developed, but a Bayesian age-period-cohort (BAPC) model built upon integrated nested Laplace approximations (INLA) [35] yields relatively higher coverage and better performance for all evaluated parameter combinations [36]. To prevent some sampling problems caused by Markov chain Monte Carlo (MCMC), this MCMC-free BAPC approach was applied to predict future cancer mortality within a fully Bayesian inference setting and provide outputs of interest simply, such as projected age-standardized and age-specific rates. Convergence checks are not necessary for this technique [35]. The projections of age-standardized cancer mortality rates for each sex, age group (younger or older than 60 years) and migrant status, taking into account age, period, and birth cohort effects, were performed based on the weights of population age groups from the WHO World Standard population [37], with 95% prediction intervals. Mann-Kendall trend test was applied to verify the projection trend.

All analyses were performed via R version 4.2.1 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria, 2013, http://www.R-project.org/). The APC models were established using the Epi package, and the projections based on Bayesian APC models were performed with the BAPC package.

Patient and Public Involvement

None.

Results

Figure 1 and eFigure 1(a-e) in **Supplementary Material** illustrate the estimates of age (assessed by cancer mortality), cohort and period effects (assessed by relative risk) based on APC models among three migrant groups for men and women with six types of cancers,

respectively. All the mortality rates for each gender and immigration status exhibit notable increasing trends with age. Age, cohort and period effects of six types of cancer for immigrants who stayed in Hong Kong for ≤10 years revealed relatively more pronounced fluctuations and deviations from those effects in other two immigration groups. Significant increasing trends of age effect occurred in all types of cancer, regardless of gender and immigration status. For example, while relatively insignificant differences in lung cancer mortality rates by immigration status among females, male immigrants who remained in Hong Kong for >10 years had higher lung cancer mortality rates at ages above 50 years and those who arrived ≤10 years had lower lung cancer mortality at ages below 62 years compared to local men Figure 1. In addition to compatible dynamics of period effect for locals and long-stay immigrants, similar change of relative risks by birth cohort for locals and long-stay immigrants in lung, colon, liver and stomach cancers occurred before 1945, whereas significant differences of relative risks by birth cohort between these two immigration groups occurred after 1960 (Figure 1 & eFigure 1(a,b,d)). Locals and long-stay immigrants in pancreatic and prostate cancer perform almost similar change of relative risks by birth cohort effects all the time (eFigure 1(c,e)). Short-stay immigrants who have stayed in Hong Kong for ≤10 years had more fluctuating relative risks affected by period effects before 2020 than those for locals and long-stay immigrants. Lack of young cases, especially young short-stay immigrants, of prostate cancer leads to significant deviations and variances in age and cohort effects.

Figure 2-4, eFigure 2-6 in **Supplementary Material** illustrate the age-standardized mortality rates of six types of cancer from 1998 to 2021 and their projections by sex, immigrant status and age groups from 2022 to 2030, taking into account age, period, and birth cohort effects. Means and standard deviations of predictive mortality rates are shown in eTable 1-6 in **Supplementary Material**. For all ages projection (Figure 2 & eFigure 2-6), monotone decreasing trends or plateau of forecasting occur for both genders and all immigration groups in cancers, except for increasing trends for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer (p-value < 0.05) and immigrants who have stayed in Hong Kong for > 10 years with pancreatic cancer (p-values < 0.05). Most of predictive trends for younger cases (<60 years) and older cases (≥60 years) reach a consensus with those for all ages population, except for two phenomenon: 1.) mortality rates of lung cancer for men immigrants ≤10 that insignificant trend for all ages (p-value > 0.05) vs. decline for younger cases (p-value < 0.05) vs. increase for older cases (p-value < 0.05); 2.) mortality rates of liver cancer for men immigrants >10 that decline for all ages (p-value < 0.05) vs. decline for younger cases (p-value < 0.05) vs. insignificant trend for older cases (p-value > 0.05). Men will be at higher risk of mortality rates of cancers (excluding prostate cancer) than women in the future for all three age groups (all ages, young and older than 60 years). Given the future developing trends,

immigrants, especially the group of immigrant who have stayed in Hong Kong for >10 years with lung, liver, pancreatic, prostate and colon cancer, will have relatively higher mortality rates in each year for each gender compared with locals and pronounced decline in predictive means (all p-values < 0.05). Some particular cases occur in the projection of prostate cancer that young long-stay male immigrants (0.44 deaths/100,000) aged less than 60 will be at lower mortality rate than locals (0.69 deaths/100,000) in 2030 (eTable 6). Compared with other cancers and immigration groups, male immigrants who have stayed in Hong Kong for >10 years with lung cancer would perform the most significant decline in predictive mean from 100.18 to 79.55 deaths per 100,000 population (average 2.92 deaths/100,000 per annum) (eTable 1), while the same immigration group with pancreatic cancer would indicate the most significant uptrend in each year of 17.87 deaths and 23.49 deaths per 100,000 population in 2022 and 2030, respectively (average 0.62 deaths/100,000 per annum) (eTable 4).

Discussion

Early detection of cancer is positive and instructive for increasing chances of cure. Nevertheless, the high mortality rate of cancer results from late diagnosis among most patients after progression to more advanced or severe stages. Individuals at high risk of cancer, such as smokers, alcoholics or those who are frequently exposed to susceptible circumstances, should be screened for early detections to increase opportunities for cure [38]. Therefore, the differences in mortality rates among immigration groups are synonymous with detection means, therapies, and social history in disparate periods and areas.

While the changes in mortality rates by age for long-stay immigrants reached approximate harmony with those for locals, the changes in mortality rates by age for short-stay immigrants revealed clear differences with those for other two populations. The group of long-stay immigrants had a higher risk of death from lung, colon and liver cancers than the other two immigration groups after the age of 60 years. Short-stay male immigrants were less likely to die from lung cancer before the age of 65 years. The contrast in age effects among the immigration groups was partially consistent with studies [25, 39] that highlighted the age effects for locals and immigrants on breast cancer mortality in Hong Kong and lung cancer incidence in Sweden, as they both showed similar trends and magnitudes between locals and immigrants before the age of 60 years. They are also compatible with the results in [40] that diagnosis of liver cancer is the most frequent among populations at 55 to 65 years old. According to these trends, young individuals, especially new young immigrant men, who have benefited from all-rounded development in mainland China and Hong Kong, are more likely to seek early detection and be treated for cancers using more advanced treatments [41].

Differences in birth cohort effects among immigrant groups partially comply with the interpretation above.

We observed significant trends of cohort effects among locals and immigrants. These findings are partially consistent but subtly different from previous findings, regarding the effect of immigration status on cancers. Zhao et al. [25] described multiple peaks of cohort effects on breast cancer mortality between locals and immigrants in Hong Kong, as well as a significant decline of cohort effects after 1950. In contrast, Sung et al. [42] investigated the difference in breast cancer incidence between Chinese Americans and non-Hispanic whites in the U.S. and emphasized that Chinese Americans were at lower risk of breast cancer than non-Hispanic whites born in the same year. Here, we interpret the cohort-driven trends resulting from the intricacy of social history and lifestyle. Compared to a relatively stable social development in Hong Kong, representing downward trends of relative risks for locals, wars and social instability in mainland China resulted in several immigration waves from mainland China to Hong Kong before 1950. Additionally, remarkable increasing trends were recorded for new immigrants after 1950, which corresponded to the economic downturn after wars and famine between 1959 and 1961 during their youth [43]. The increasing trends for new immigrants and similar trends for locals and long-stay immigrants were consistent with the finding that nutrient deficiency contributes to higher risk of severe mortality rates of cancers [44]. Furthermore, we speculate that these trends, especially those for locals and long-stay immigrants, are most likely attributed to social development and personal behaviors, such as daily habits, occupational history, different diagnoses and treatments, and domestic environmental exposures. It's notable that short-stay immigrants suffered from lower risk of death from colon cancer for all ages (eFigure 1a in **Supplementary Material**). As locals and immigrants in Hong Kong transitioned to a more westernized lifestyles, higher consumption of meat was associated with a higher risk of these types of cancer, whereas consumptions of vegetables had a strong protective effect against pancreatic cancer, and moderate consumption of coffee appeared to be beneficial against lung cancer [45,46]. Further studies on potential risk factors are required.

Short-stay immigrants had more fluctuating and non-stationary but inconspicuous relative risks by period effects before 2021 than locals and long-stay immigrants. Cumulatively, an arch pattern and fluctuating curve depicting period effects externally resulted in an arch pattern of age-standardized mortality rates for short-stay immigrant women and irregular rates for short-stay immigrant men before 2021. The external performance of different period effects on mortality rates could be most likely attributed to the higher effect of different lifestyles and social development on new immigrants than on long-stay immigrants and locals in Hong Kong. With respect to the age-standardized mortality rates and projections,

consistent with previous findings [47,48], we predict that the mortality rates of cancer in Hong Kong after 2021 will continue to decline or remain relatively stable, consistent with the trends before 2020, except for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer. Men will be at higher risk of mortality rates of cancer than women, regardless of immigration status. They are also compatible with the results in [4] that men suffer from higher risk of these types of cancer than women, excluding prostate cancer. Furthermore, new immigrant women will be at lower risk than local women, even though long-stay immigrants will suffer from higher mortality rates than locals in the future. Potential interpretations could be consistent with those for birth cohort effects, as age and period effect are considered as confounders of cohort effect.

In the past few decades, spurred by an increasing burden of high incidence and mortality rates of cancer, several studies focused on the inherent identification dilemma of three effects in the APC model. Further, complicated population distribution and immigration status in Hong Kong, one of the areas with the highest population density and migration frequency in the world, have intricate causes and inherent dynamics of cancer and other diseases. To our knowledge, few studies have assessed the relationship between immigration status and cancer mortality. Therefore, this study is original to examine the effect of the length of stay in Hong Kong and origins of previous residence on cancer deaths, which is instructive for further immigration policy making and targeted strategies of disease detection and intervention. However, this study had several limitations. Given the non-identifiability problem in age-period-cohort models, we could only depict trends and variations among different immigration and sex groups, as illustrated in figures, and insufficiently perform the estimates of the contributions of three effects or subgroups to mortality rates. Furthermore, we adopted cubic smoothing spline to estimate populations of immigrants and locals due to the large proportion of unspecified immigration status from official demographic projections. A few acceptable cases resulted in a limited type of cancer so that some common cancers such as ovary and cervix, were discarded. Since the issue of quantification, the future perspective of cancer therapies and techniques have not been considered in the model of projection.

Conclusion

We conclude that immigrants, especially short-stay immigrants, had more pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Men will be at a higher risk of mortality rates of six types of cancer than women in the future. Male immigrants who have

stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer would perform significant uptrend in the future, while other immigration groups for each type of cancer would continue to decline or remain relatively stable. Immigrants for each gender in Hong Kong would suffer from higher mortality risks of cancers than locals in the future.

Declaration

Ethical approval and consent to participate

Ethical approval and consent to participate are not applicable. This study does not involve human participants. Data was obtained from the Census and Statistics Department of Hong Kong.

Consent for publication

Not applicable.

Data Availability Statement

Data are available upon reasonable request.

Author contributions

Yanji Zhao: Methodology, Formal analysis, Data Curation, Writing - Original Draft, Visualization
Zian Zhuang: Methodology, Formal analysis, Data Curation, Writing - Review & Editing
Lin Yang: Validation, Writing - Review & Editing
Daihai He: Conceptualization, Writing - Review & Editing, Supervision

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Conflict of interest

None declared.

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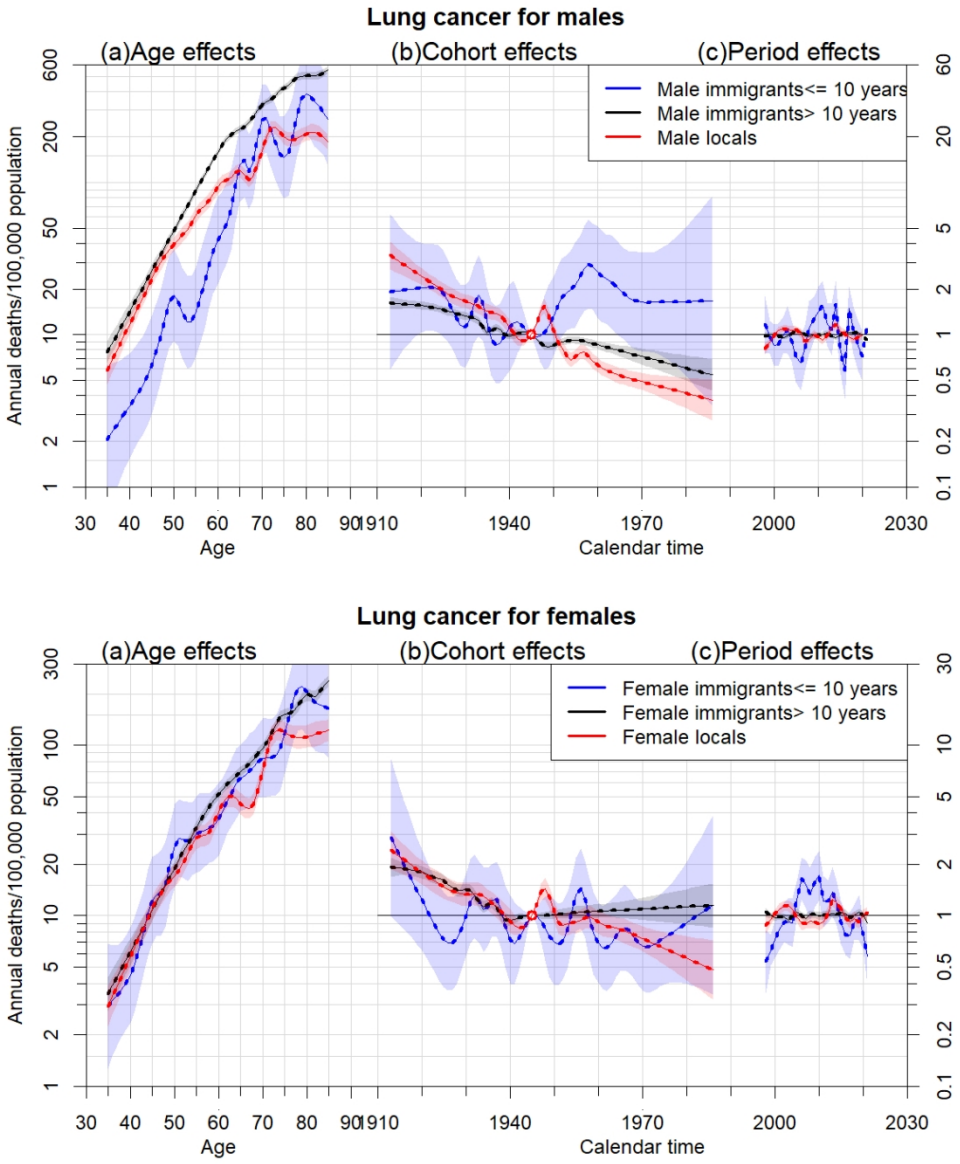
Figure 1. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

Figure 2. Projections of lung cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 3. Projections of lung cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 4. Projections of lung cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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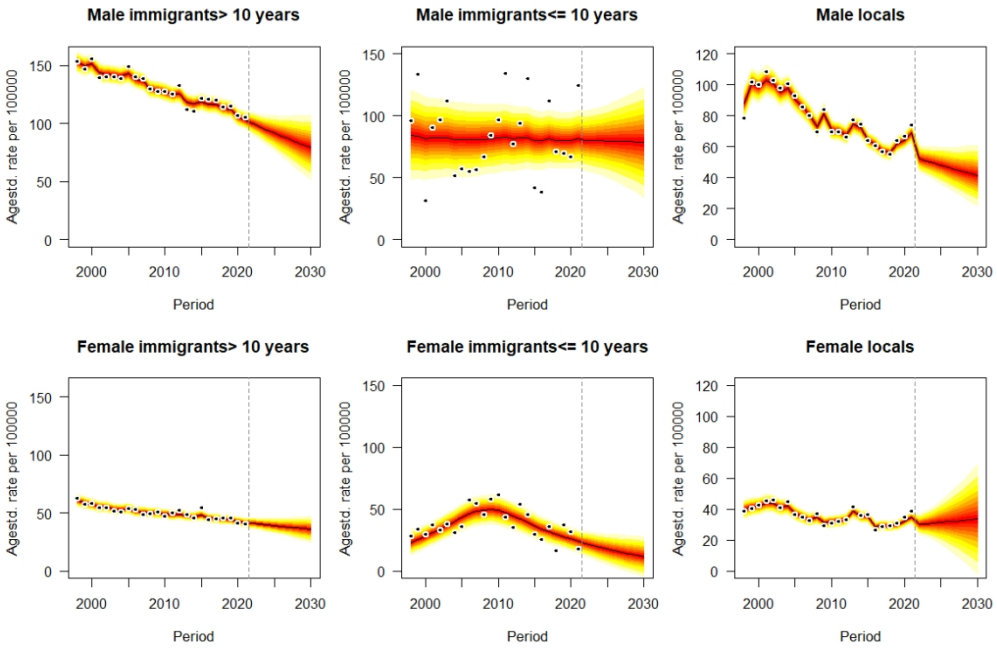

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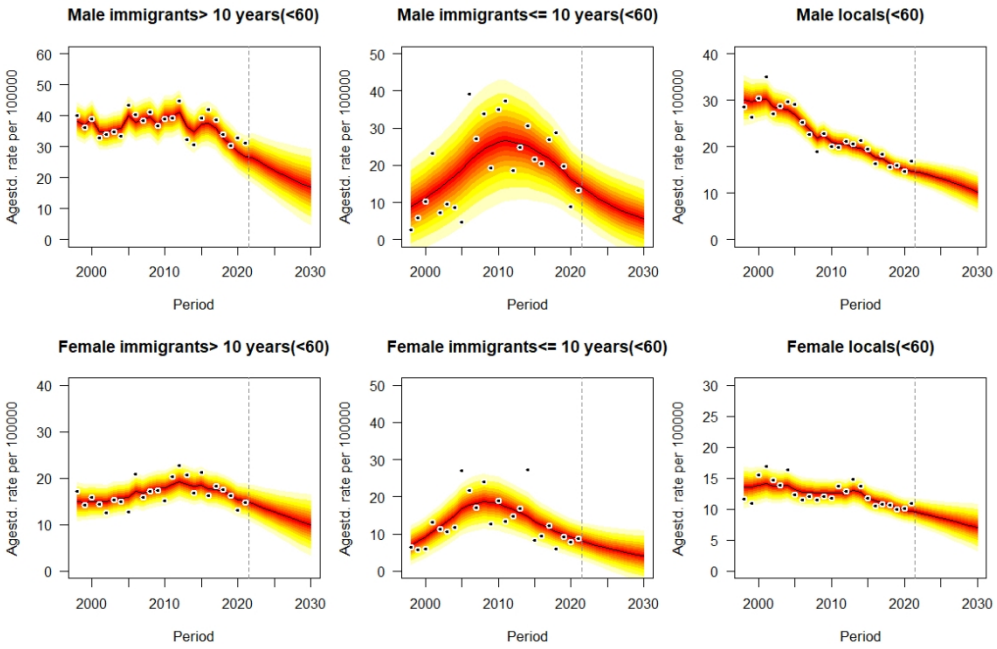

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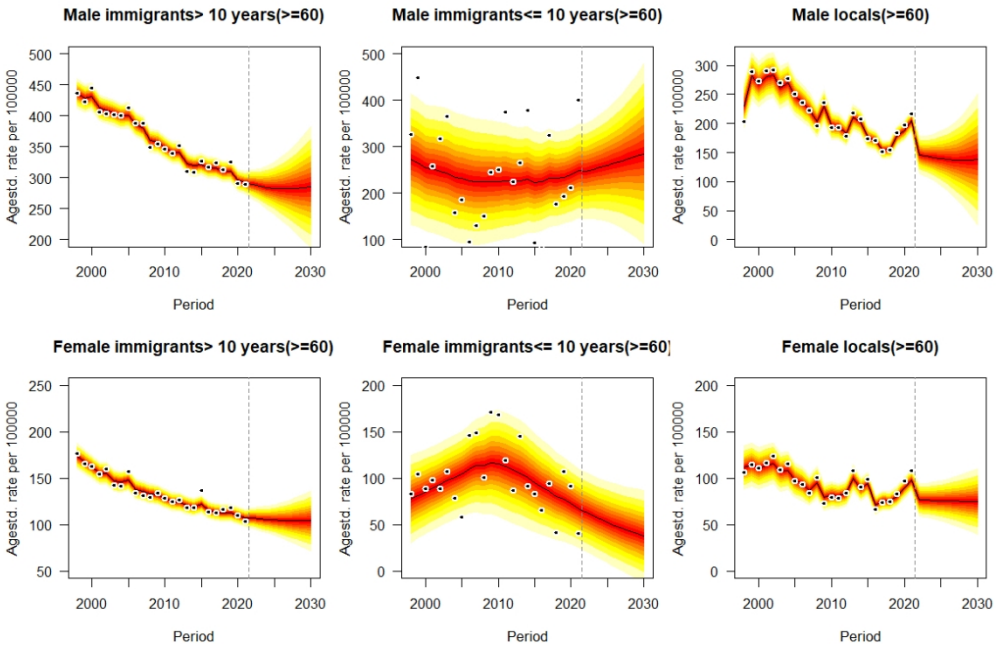

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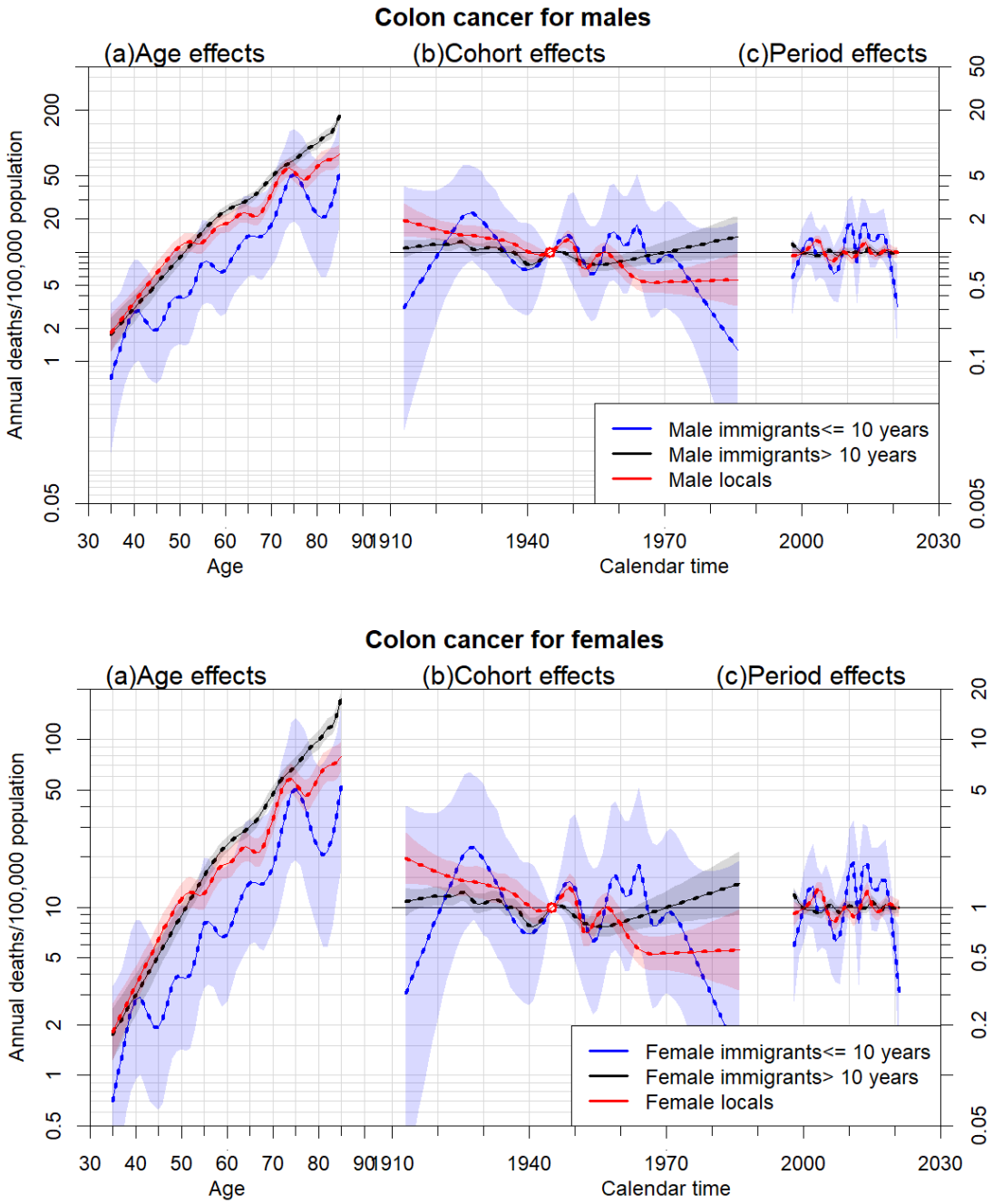
Supplementary Material for

"An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030"

APC Figures

Projection Figures

Tables



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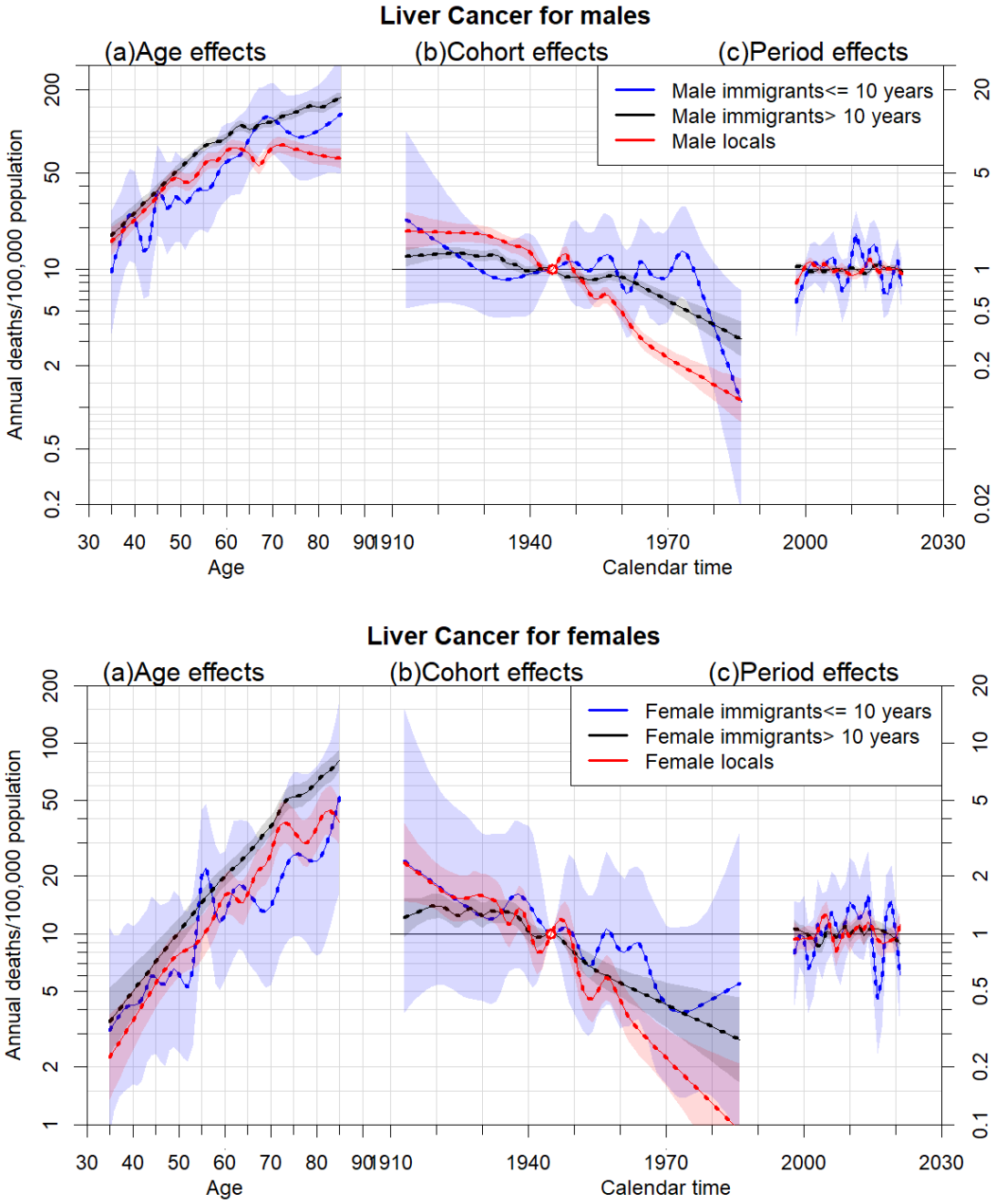
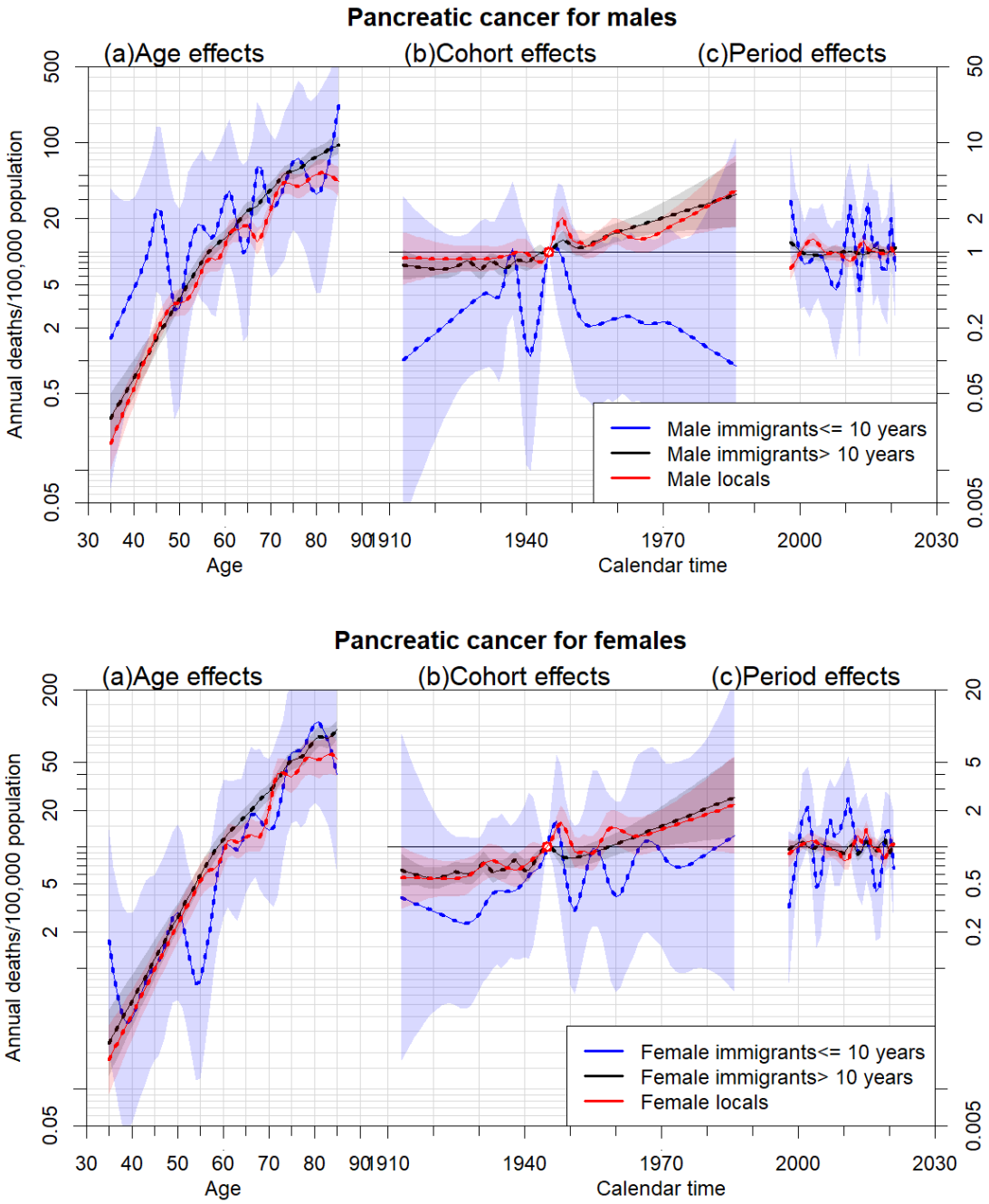
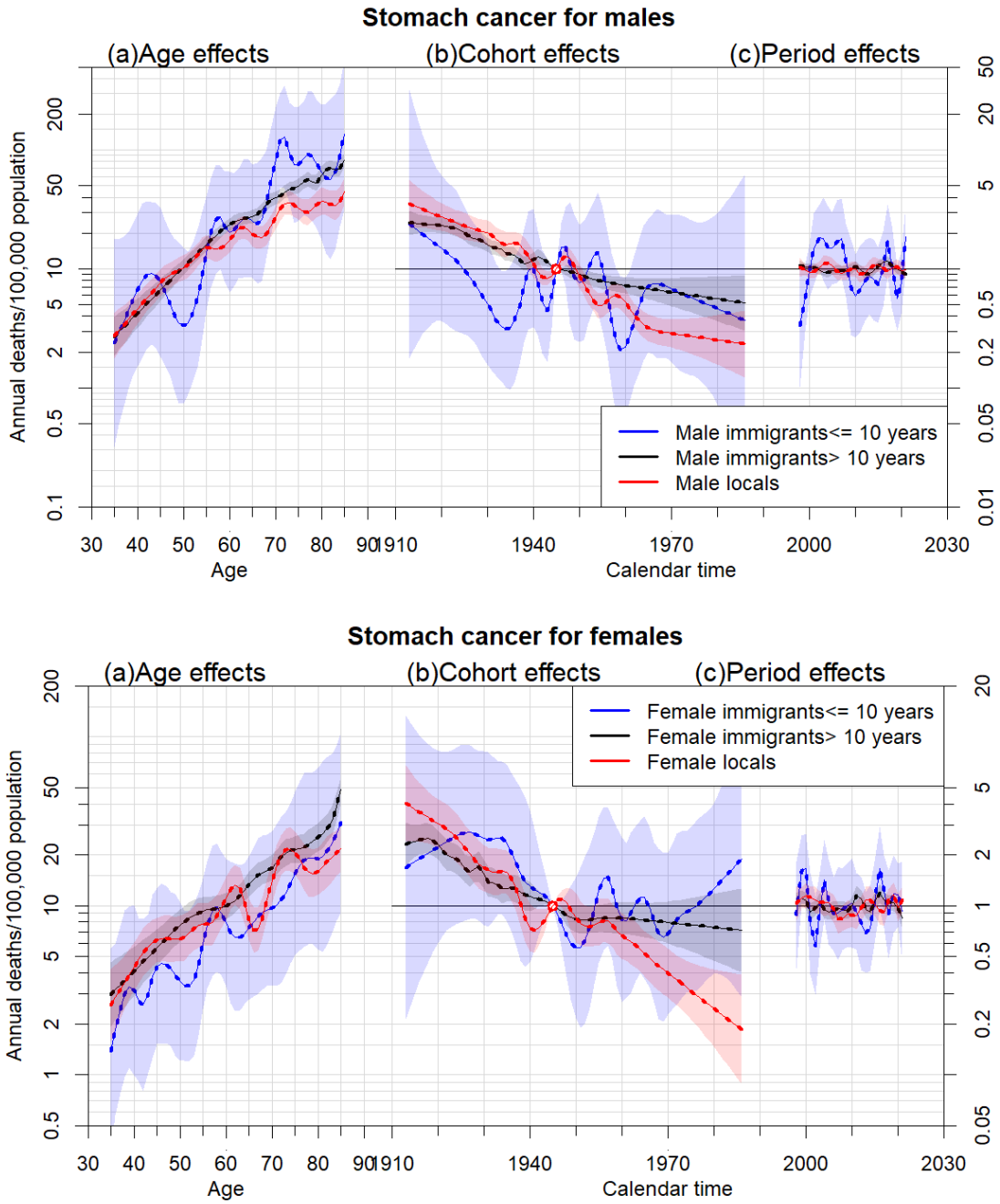


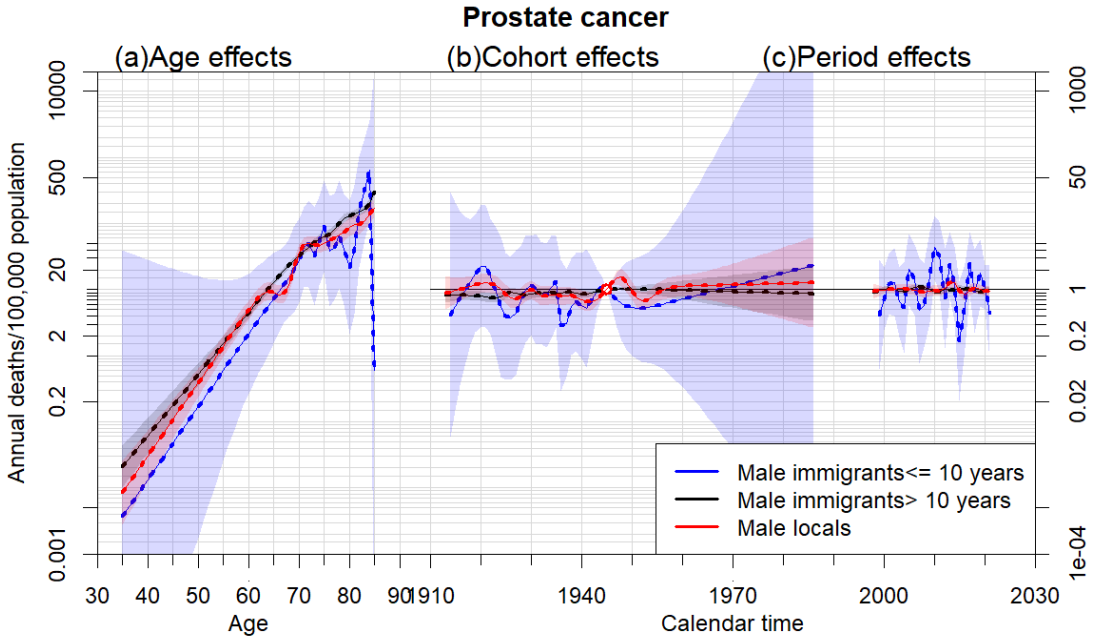
eFigure 1(b). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female liver cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



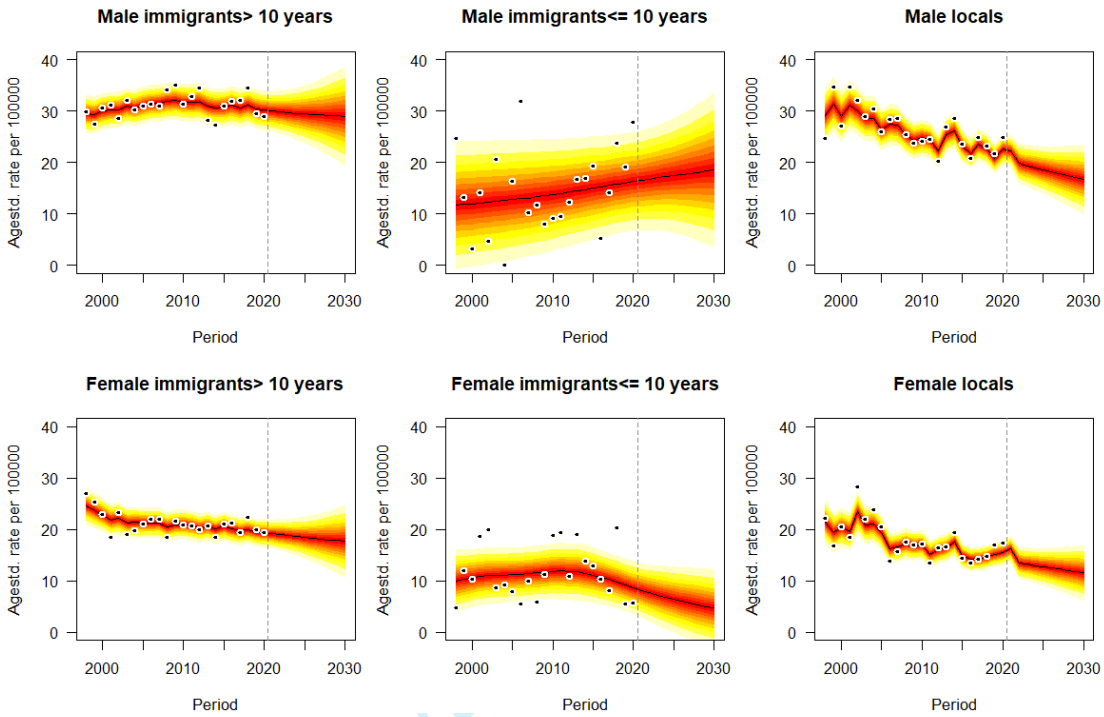
eFigure 1(c). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female pancreatic cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



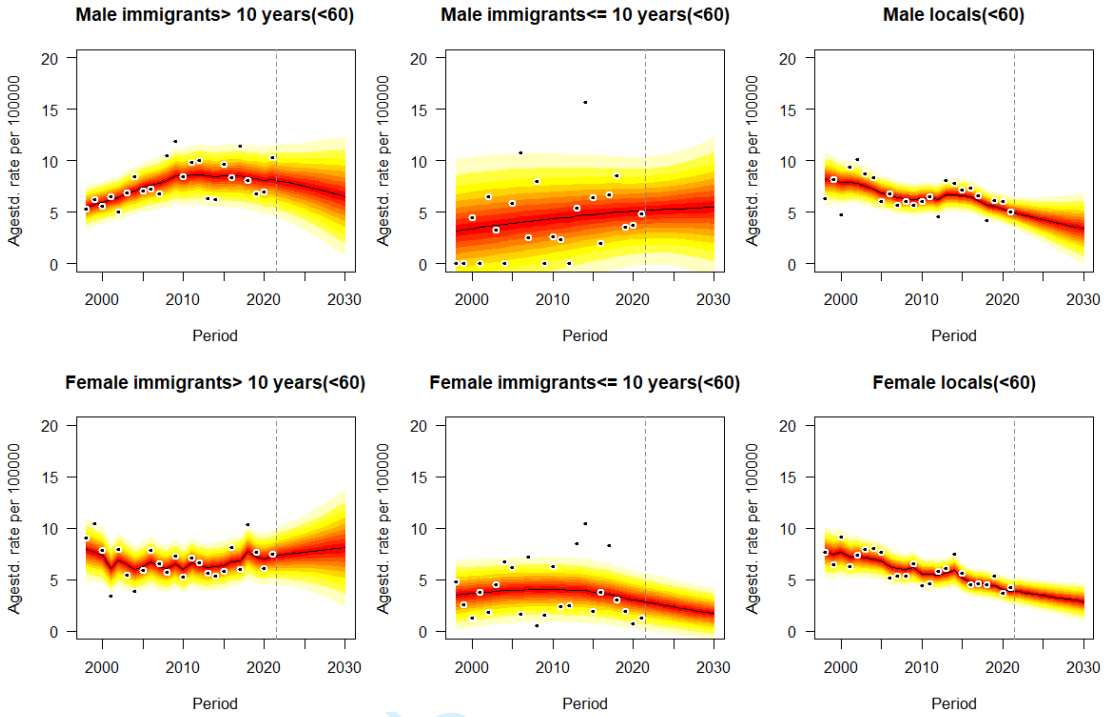
eFigure 1(d). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female stomach cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



eFigure 1(e). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male prostate cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



eFigure 2(a). Projections of colon cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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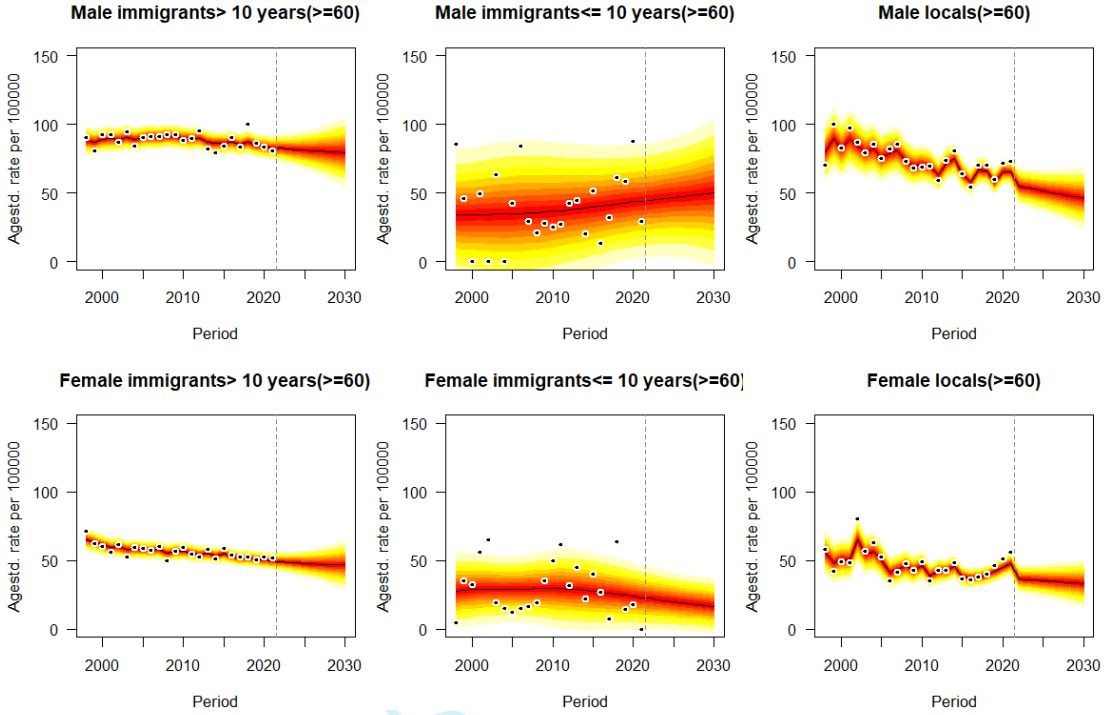
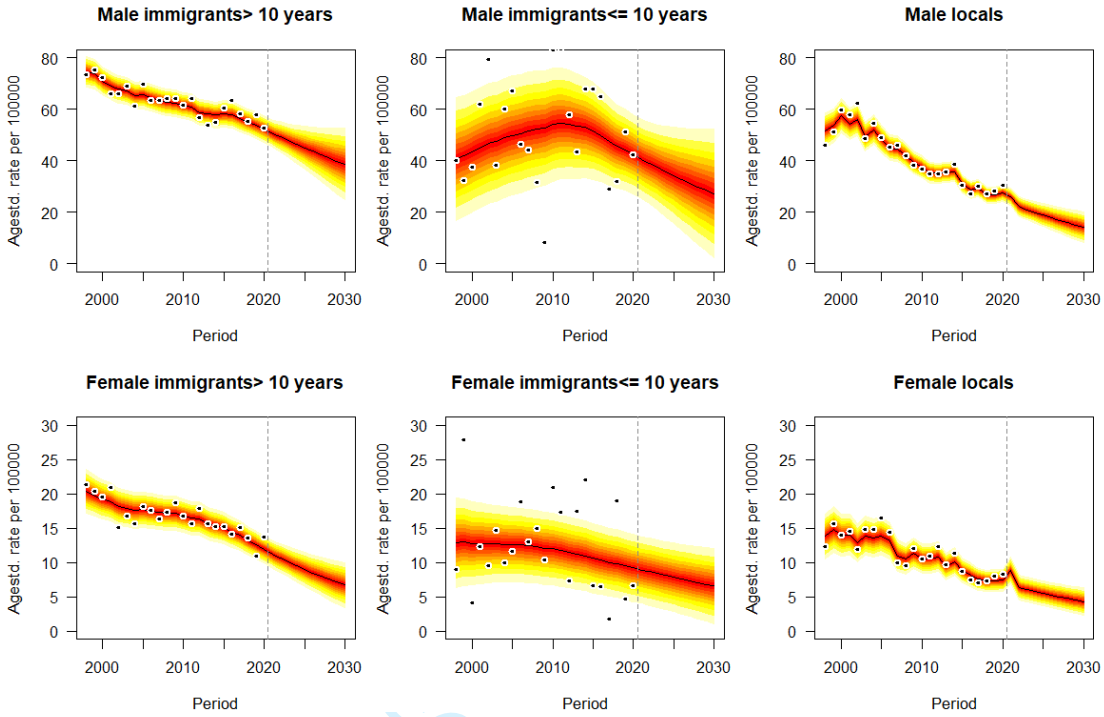
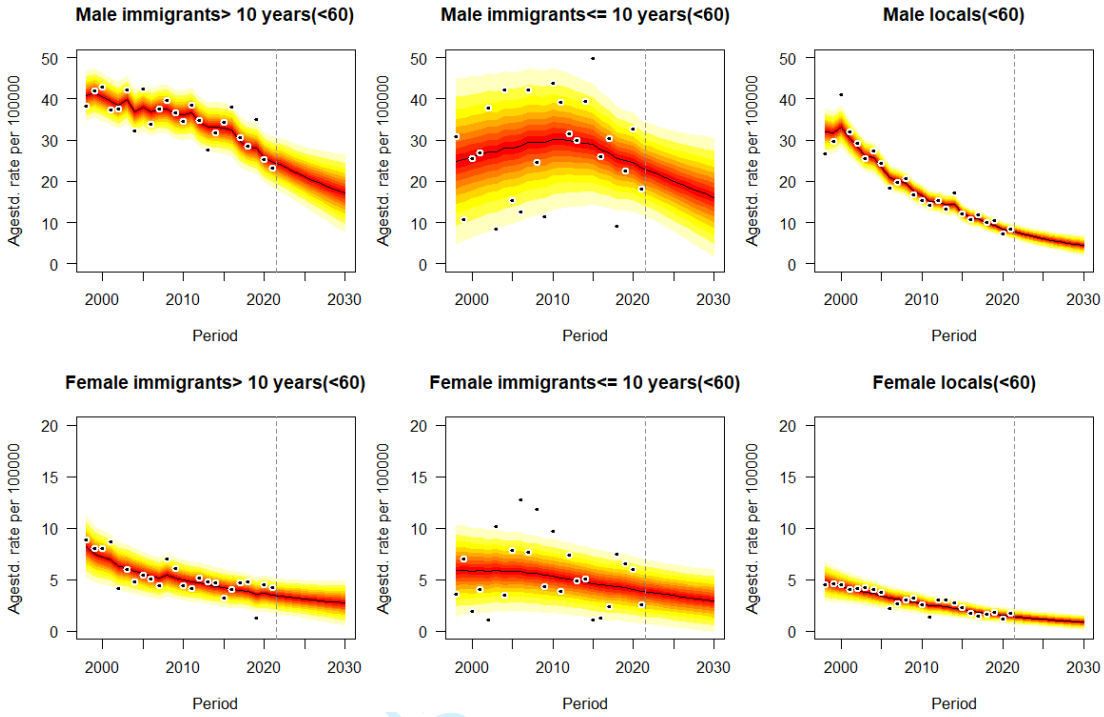


eFigure 2(c). Projections of colon cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 3(a). Projections of liver cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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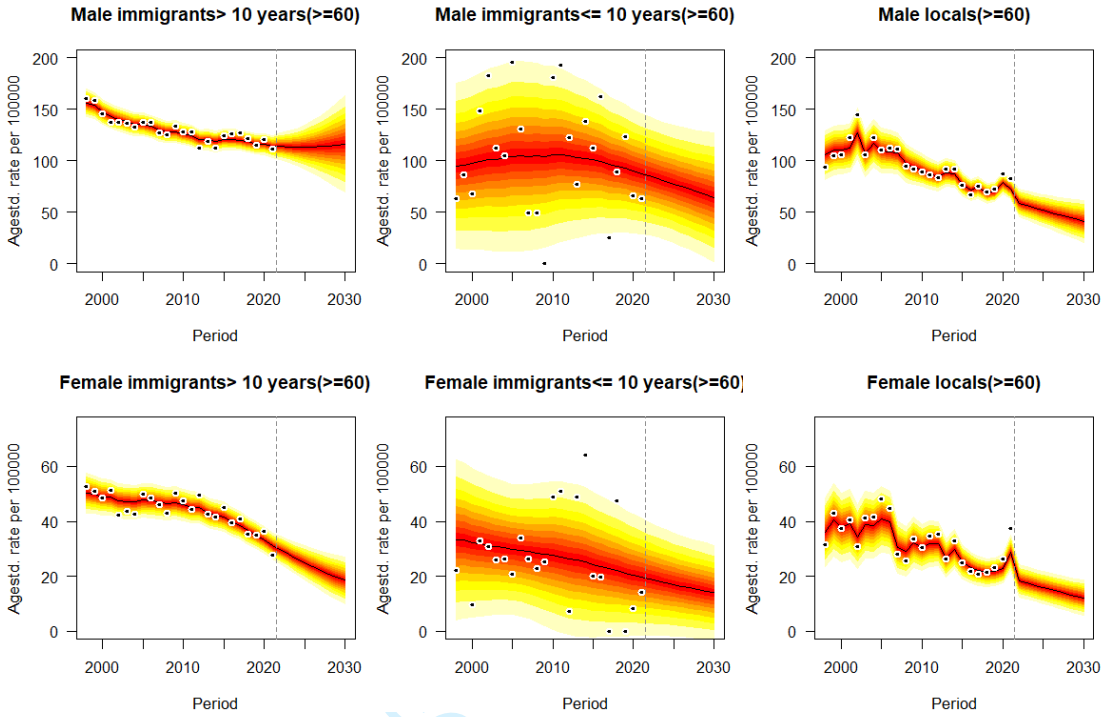

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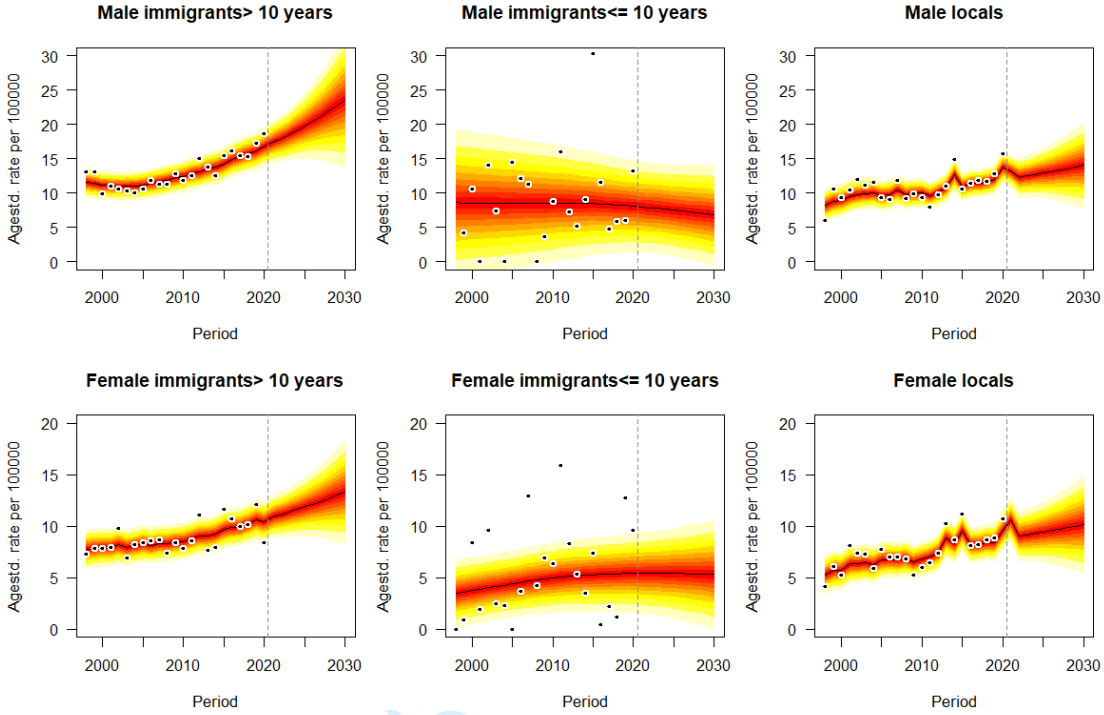
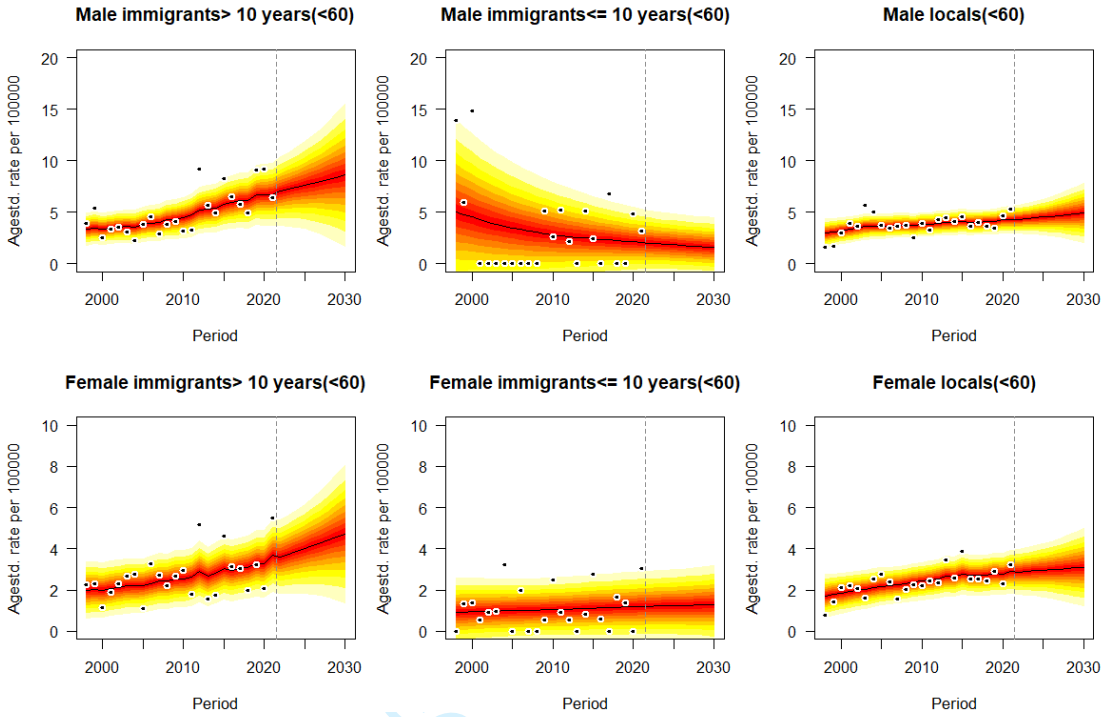


eFigure 4(a). Projections of pancreatic cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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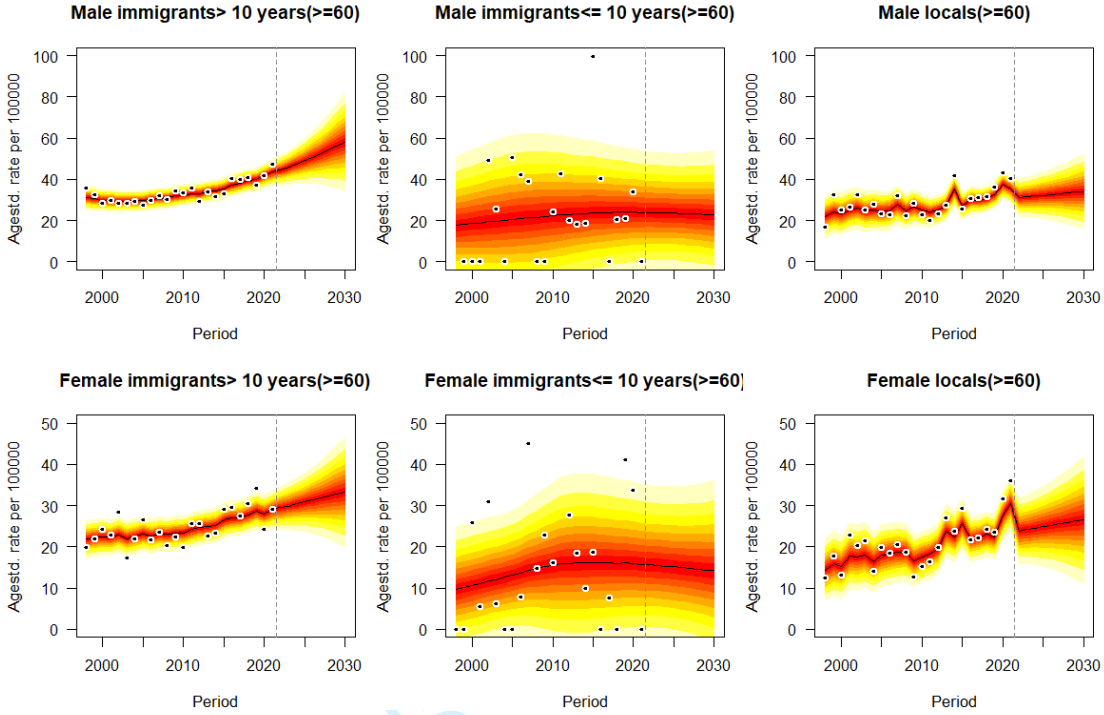

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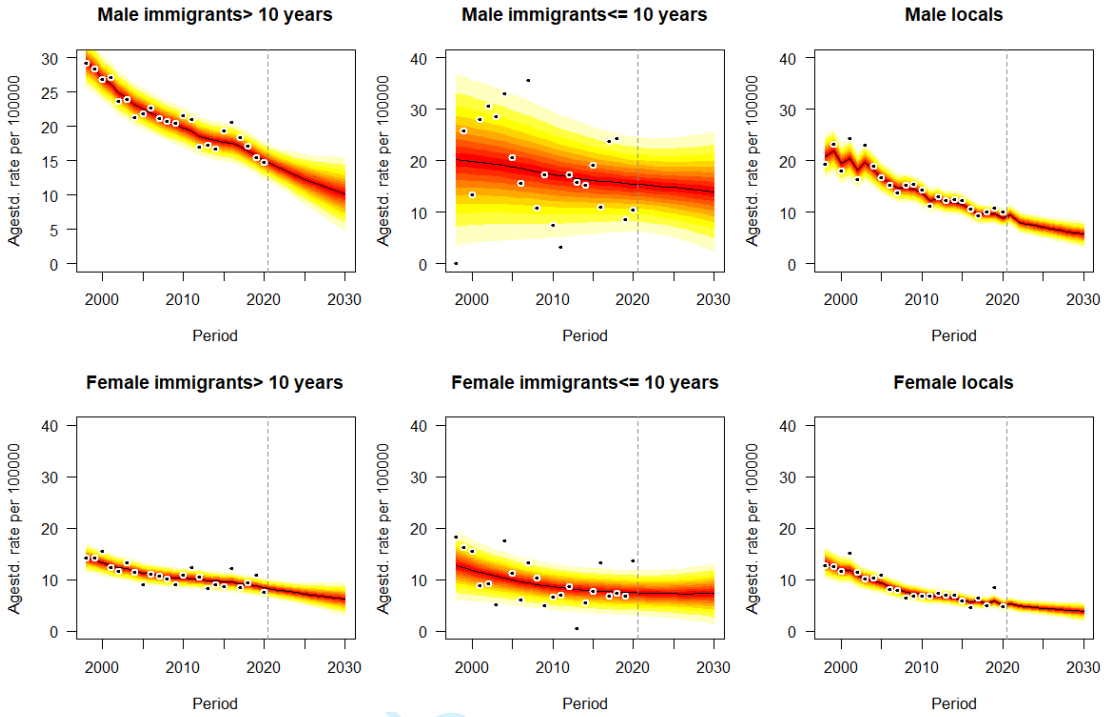
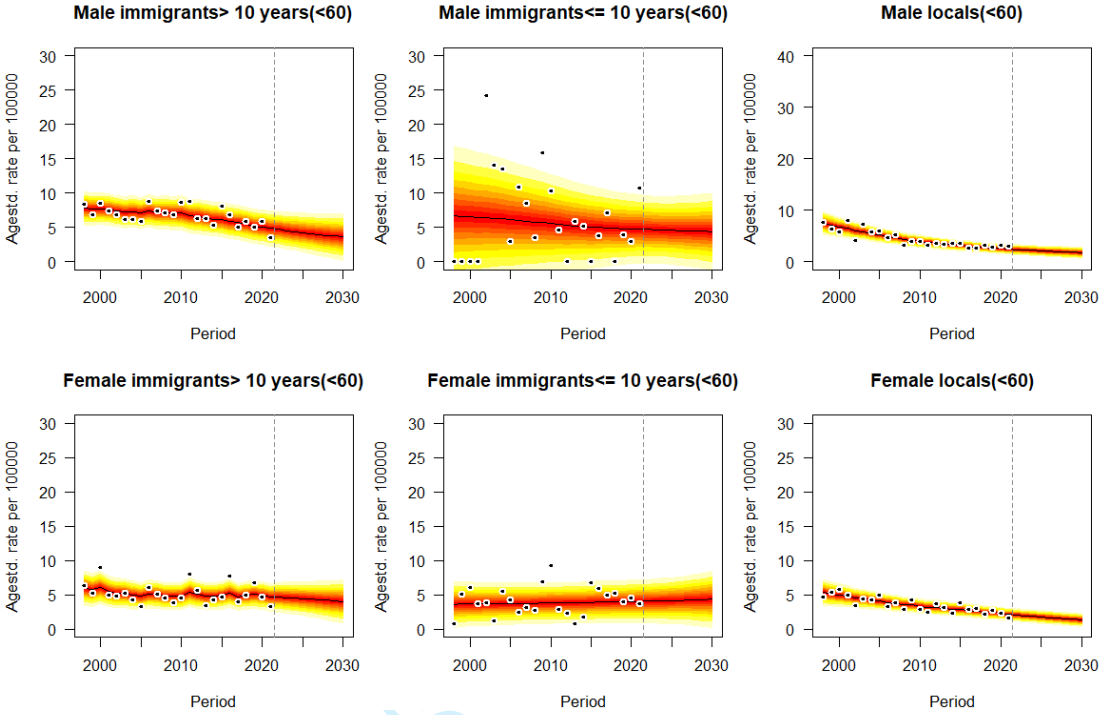


eFigure 5(a). Projections of stomach cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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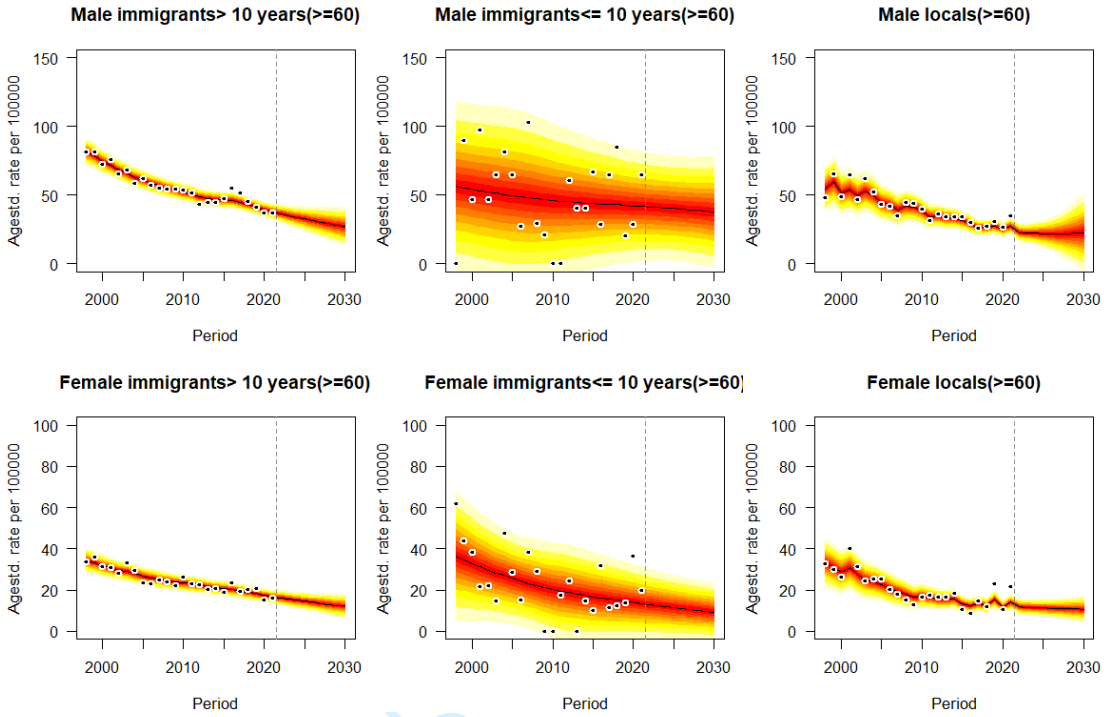

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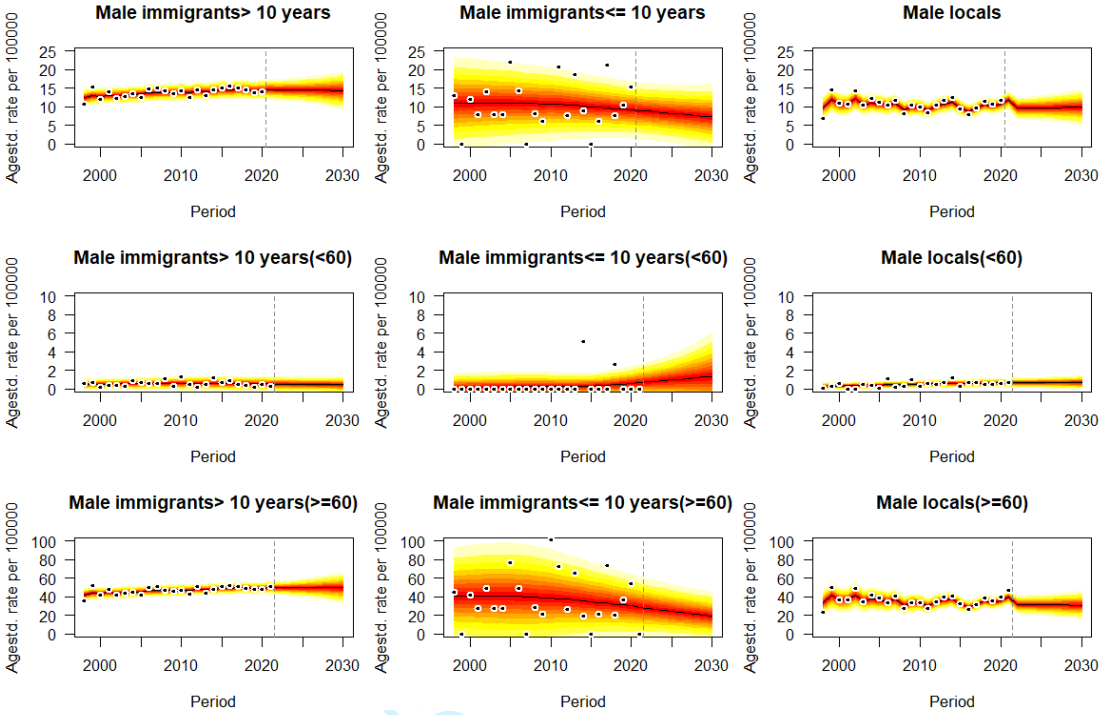

eFigure 6. Projections of prostate cancer mortality rates for males by immigrant status and age groups (less than, greater than or equal to 60 years old) from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Predictive mean of age-standardized mortality rates of lung cancer per 100,000 population									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	41.34 (1.86)	40.58 (2.27)	39.87 (2.75)	39.19 (3.28)	38.53 (3.86)	37.89 (4.46)	37.26 (5.09)	36.65 (5.74)	36.04 (6.4)
Female immigrants ≤ 10	22.22 (4.67)	20.56 (5.38)	19.01 (6.10)	17.57 (6.80)	16.24 (7.45)	15.00 (8.04)	13.85 (8.56)	12.79 (9.01)	11.81 (9.39)
Female locals	30.22 (3.54)	30.63 (4.77)	31.05 (6.38)	31.48 (8.29)	31.9 (10.47)	32.32 (12.87)	32.73 (15.48)	33.15 (18.31)	33.55 (21.33)
Male immigrants >10	100.18 (4.18)	97.18 (5.33)	94.34 (6.72)	91.71 (8.24)	89.15 (9.84)	86.66 (11.47)	84.19 (13.11)	81.81 (14.74)	79.55 (16.37)
Male immigrants ≤10	79.90 (10.41)	79.81 (11.82)	79.72 (13.42)	79.62 (15.19)	79.50 (17.09)	79.32 (19.09)	79.08 (21.18)	78.78 (23.32)	78.41 (25.53)
Male locals	52.27 (4.86)	50.83 (5.39)	49.56 (6.13)	48.18 (6.97)	46.64 (7.84)	45.13 (8.76)	43.83 (9.76)	42.67 (10.8)	41.43 (11.8)
Female immigrants>10(<60y)	14.51 (1.50)	13.90 (1.76)	13.29 (2.04)	12.71 (2.33)	12.13 (2.62)	11.57 (2.91)	11.02 (3.18)	10.49 (3.43)	9.98(3.68)
Female immigrants ≤ 10(<60y)	7.79 (1.95)	7.18(2.23)	6.62(2.53)	6.10(2.81)	5.63(3.08)	5.19(3.32)	4.79(3.53)	4.42(3.72)	4.09(3.88)
Female locals(<60y)	9.48 (0.89)	9.17(1.02)	8.87(1.16)	8.57(1.32)	8.27(1.49)	7.97(1.65)	7.68(1.82)	7.38(1.98)	7.09(2.13)
Male immigrants>10(<60y)	26.36 (3.58)	24.96 (3.94)	23.64 (4.35)	22.38 (4.79)	21.17 (5.23)	20.03 (5.67)	18.96 (6.10)	17.96 (6.51)	17.03 (6.90)
Male immigrants ≤ 10(<60y)	13.38 (3.71)	12.02 (4.17)	10.79 (4.59)	9.68 (4.95)	8.69 (5.24)	7.79 (5.46)	6.98 (5.61)	6.25 (5.69)	5.59 (5.72)
Male locals(<60y)	14.45 (1.15)	14.03 (1.29)	13.61 (1.46)	13.14 (1.64)	12.65 (1.82)	12.13 (2.01)	11.55 (2.17)	10.93 (2.31)	10.26 (2.43)
Female immigrants >10(≥ 60y)	107.21 (5.17)	106.26 (6.24)	105.52 (7.54)	104.94 (9.04)	104.51 (10.72)	104.21 (12.57)	104.07 (14.61)	104.06 (16.78)	104.16 (19.14)
Female immigrants ≤ 10(≥60y)	63.84 (15.72)	59.88 (17.50)	56.14 (19.31)	52.60 (21.03)	49.27 (22.66)	46.14 (24.16)	43.20 (25.52)	40.44 (26.74)	37.85 (27.81)
Female locals(≥60y)	76.53 (10.11)	76.22 (10.85)	75.94 (11.79)	75.69 (12.94)	75.49 (14.28)	75.32 (15.80)	75.19 (17.48)	75.10 (19.33)	75.03 (21.32)
Male immigrants>10(≥60y)	289.8 (11.7)	286.6 (15.19)	284.28 (19.51)	282.78 (24.49)	281.99 (30.07)	281.88 (36.31)	282.31 (43.15)	283.37 (50.66)	285.03 (58.86)
Male immigrants ≤ 10(≥60y)	247.01 (36.85)	251.24 (42.94)	255.62 (50.06)	260.14 (58.14)	264.82 (67.14)	269.61 (77.01)	274.52 (87.75)	279.55 (99.34)	284.69 (111.81)
Male locals(≥60y)	146.29 (18.46)	143.54 (20.58)	141.84 (23.97)	140.07 (28.24)	138.14 (33.39)	136.65 (39.82)	136.49 (47.87)	137.24 (57.47)	138.26 (68.52)

eTable 1. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of lung cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030.

Predictive mean of age-standardized mortality rates of colon cancer per 100,000 population									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	18.95 (1.13)	18.77 (1.37)	18.59 (1.66)	18.42 (1.98)	18.27 (2.33)	18.12 (2.71)	17.98 (3.11)	17.85 (3.53)	17.73 (3.96)
Female immigrants ≤ 10	7.70 (2.51)	7.25 (2.81)	6.82 (3.11)	6.42 (3.37)	6.03 (3.61)	5.67 (3.83)	5.33 (4.01)	5.01 (4.17)	4.71 (4.31)
Female locals	13.47 (1.61)	13.24 (1.72)	13.01 (1.87)	12.77 (2.04)	12.53 (2.24)	12.29 (2.46)	12.06 (2.68)	11.82 (2.92)	11.59 (3.16)
Male immigrants >10	29.82 (1.46)	29.66 (1.79)	29.52 (2.19)	29.41 (2.63)	29.30 (3.11)	29.21 (3.64)	29.14 (4.19)	29.06 (4.78)	28.98 (5.39)
Male immigrants ≤10	16.77 (3.77)	17.02 (4.18)	17.23 (4.64)	17.45 (5.14)	17.67 (5.69)	17.88 (6.27)	18.09 (6.91)	18.31 (7.56)	18.50 (8.26)
Male locals	19.81 (2.07)	19.39 (2.22)	18.97 (2.42)	18.57 (2.61)	18.18 (2.85)	17.81 (3.12)	17.43 (3.40)	17.06 (3.71)	16.71 (4.03)
Female immigrants >10(<60y)	7.36 (1.12)	7.46 (1.28)	7.56 (1.46)	7.65 (1.68)	7.74 (1.92)	7.83 (2.19)	7.92 (2.48)	8.01 (2.79)	8.09 (3.13)
Female immigrants ≤ 10(<60y)	2.82 (0.86)	2.65 (0.91)	2.51 (0.97)	2.36 (1.02)	2.22 (1.07)	2.08 (1.11)	1.95 (1.14)	1.83 (1.18)	1.72 (1.22)
Female locals(<60y)	3.87 (0.50)	3.73 (0.54)	3.61 (0.59)	3.47 (0.65)	3.34 (0.70)	3.22 (0.76)	3.11 (0.82)	2.99 (0.88)	2.88 (0.94)
Male immigrants >10(<60y)	7.9 8(1.17)	7.85 (1.38)	7.71 (1.60)	7.54(1.83)	7.36(2.08)	7.17(2.32)	6.97(2.57)	6.76(2.81)	6.55(3.05)
Male immigrants ≤ 10(<60y)	5.18 (1.58)	5.22 (1.75)	5.26 (1.93)	5.30(2.14)	5.34(2.36)	5.38(2.59)	5.43(2.84)	5.47(3.11)	5.51(3.38)
Male locals(<60y)	4.88 (0.63)	4.66 (0.79)	4.46 (0.96)	4.26(1.13)	4.08(1.31)	3.91(1.48)	3.73(1.65)	3.57(1.82)	3.42(1.97)
Female immigrants >10(≥60y)	49.21 (2.99)	48.70 (3.56)	48.26 (4.26)	47.87 (5.05)	47.54 (5.94)	47.26 (6.90)	47.05 (7.94)	46.91 (9.06)	46.81 (10.26)
Female immigrants ≤ 10(≥60y)	22.44 (6.56)	21.69 (6.96)	20.95 (7.38)	20.23 (7.80)	19.52 (8.23)	18.84 (8.66)	18.17 (9.08)	17.51 (9.49)	16.86 (9.90)
Female locals(≥60y)	36.69 (5.74)	36.29 (6.06)	35.87 (6.46)	35.46 (6.95)	35.04(7.5)	34.61 (8.12)	34.19 (8.79)	33.77 (9.51)	33.34 (10.27)
Male immigrants >10(≥60y)	82.72 (4.09)	82.16 (4.95)	81.64 (5.97)	81.19 (7.12)	80.81 (8.39)	80.47 (9.77)	80.15 (11.24)	79.85 (12.81)	79.56 (14.45)
Male immigrants ≤ 10(≥60y)	44.93 (13.09)	45.62 (14.52)	46.30 (16.09)	46.96 (17.80)	47.61 (19.64)	48.25 (21.62)	48.88 (23.73)	49.51 (25.97)	50.13 (28.34)
Male locals(≥60y)	54.89 (7.65)	53.75 (8.03)	52.63 (8.52)	51.54 (9.12)	50.47 (9.8)	49.43 (10.55)	48.42 (11.37)	47.42 (12.25)	46.44 (13.16)

eTable 2. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of colon cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030.

Predictive mean of age-standardized mortality rates of liver cancer per 100,000 population									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	10.68 (0.71)	10.09 (0.85)	9.54 (1.01)	9.01 (1.16)	8.50 (1.31)	8.02(1.45)	7.57(1.59)	7.14(1.72)	6.74(1.83)
Female immigrants ≤10	8.66 (1.82)	8.38 (1.95)	8.11 (2.08)	7.84 (2.22)	7.58 (2.36)	7.32(2.49)	7.07(2.63)	6.82(2.76)	6.58(2.88)
Female locals	6.36 (0.88)	6.08 (0.90)	5.81 (0.93)	5.53 (0.97)	5.26 (1.01)	5.01(1.06)	4.77(1.11)	4.53(1.15)	4.3(1.21)
Male immigrants >10	49.22 (2.36)	47.76 (2.93)	46.35 (3.59)	45.01 (4.31)	43.67 (5.05)	42.37 (5.81)	41.1(6.56)	39.89 (7.33)	38.71 (8.08)
Male immigrants ≤10	39.03 (6.49)	37.39 (7.47)	35.81 (8.51)	34.26 (9.58)	32.76 (10.63)	31.31 (11.65)	29.91 (12.62)	28.56 (13.54)	27.25 (14.40)
Male locals	22.16 (2.09)	21.02 (2.22)	19.91 (2.39)	18.85 (2.58)	17.83 (2.79)	16.85 (3.03)	15.92 (3.21)	15.03 (3.40)	14.18 (3.59)
Female immigrants >10(<60y)	3.39 (0.52)	3.29 (0.57)	3.20 (0.63)	3.12 (0.69)	3.04 (0.75)	2.96(0.82)	2.89(0.89)	2.82(0.96)	2.75(1.03)
Female immigrants ≤ 10(<60y)	3.81 (0.91)	3.69 (0.96)	3.57 (1.02)	3.46 (1.08)	3.36 (1.15)	3.25(1.22)	3.15(1.29)	3.06(1.36)	2.97(1.43)
Female locals(<60y)	1.37 (0.2)	1.29 (0.21)	1.22 (0.23)	1.16 (0.24)	1.10 (0.26)	1.04(0.27)	0.99(0.29)	0.94(0.30)	0.89(0.31)
Male immigrants >10(<60y)	24.04 (2.35)	23.02 (2.63)	22.05 (2.94)	21.13 (3.27)	20.25 (3.61)	19.41 (3.95)	18.62 (4.30)	17.86 (4.64)	17.14 (4.98)
Male immigrants ≤ 10(<60y)	22.56 (3.96)	21.71 (4.44)	20.87 (4.94)	20.04 (5.45)	19.22 (5.95)	18.42 (6.45)	17.63 (6.91)	16.86 (7.36)	16.11 (7.78)
Male locals(<60y)	7.47 (0.74)	6.97 (0.79)	6.52 (0.86)	6.11 (0.93)	5.73 (1.01)	5.38(1.08)	5.04(1.15)	4.73(1.21)	4.44(1.27)
Female immigrants >10(≥ 60y)	29.63 (2.01)	27.99 (2.36)	26.42 (2.75)	24.92 (3.14)	23.49 (3.52)	22.13 (3.88)	20.85 (4.23)	19.64 (4.55)	18.50 (4.85)
Female immigrants ≤10(≥ 60y)	19.08 (5.81)	18.38 (6.14)	17.71 (6.48)	17.03 (6.83)	16.39 (7.16)	15.76 (7.49)	15.16 (7.80)	14.57 (8.11)	14.01 (8.39)
Female locals(≥60y)	18.41 (3.23)	17.55 (3.26)	16.72 (3.32)	15.91 (3.40)	15.11 (3.49)	14.34 (3.59)	13.59 (3.69)	12.87 (3.81)	12.17 (3.93)
Male immigrants >10(≥ 60y)	113.96 (5.95)	113.43 (7.65)	113.17 (9.70)	113.16 (12.04)	113.37 (14.66)	113.79 (17.56)	114.39 (20.73)	115.19 (24.18)	116.17 (27.91)
Male immigrants ≤10(≥ 60y)	85.14 (18.85)	82.59 (20.6)	80.02 (22.44)	77.42 (24.34)	74.83 (26.24)	72.23 (28.12)	69.64 (29.94)	67.07 (31.70)	64.52 (33.38)
Male locals(≥60y)	58.95 (7.91)	56.51 (8.20)	54.14 (8.61)	51.84 (9.12)	49.61 (9.70)	47.46 (10.33)	45.38 (11.01)	43.38 (11.68)	41.45(12.36)

eTable 3. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of liver cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030.

Predictive mean of age-standardized mortality rates of pancreatic cancer per 100,000 population									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	11.11 (0.75)	11.36 (0.91)	11.61 (1.09)	11.87 (1.31)	12.14 (1.56)	12.42 (1.84)	12.71 (2.15)	13.01 (2.48)	13.3(2.85)
Female immigrants ≤ 10	5.44 (1.56)	5.44 (1.69)	5.43(1.84)	5.42(1.99)	5.41(2.15)	5.39(2.32)	5.36(2.49)	5.34(2.66)	5.31(2.84)
Female locals	9.01 (1.22)	9.15 (1.34)	9.29(1.48)	9.43(1.64)	9.57(1.83)	9.71(2.05)	9.85(2.28)	9.99(2.54)	10.14 (2.83)
Male immigrants >10	17.87 (1.19)	18.48 (1.49)	19.11 (1.87)	19.78 (2.32)	20.47 (2.83)	21.18 (3.42)	21.92 (4.07)	22.69 (4.81)	23.49 (5.61)
Male immigrants ≤10	7.87 (2.37)	7.76 (2.53)	7.64(2.70)	7.51(2.87)	7.38(3.05)	7.24(3.23)	7.09(3.41)	6.95(3.58)	6.81(3.75)
Male locals	12.29 (1.49)	12.49 (1.64)	12.69 (1.83)	12.91 (2.06)	13.11 (2.33)	13.33 (2.63)	13.55 (2.97)	13.78 (3.34)	14.02 (3.74)
Female immigrants >10(<60y)	3.62 (0.57)	3.74 (0.66)	3.87(0.77)	4.01(0.89)	4.14(1.02)	4.28(1.18)	4.42(1.34)	4.57(1.53)	4.72(1.73)
Female immigrants ≤ 10(<60y)	1.21 (0.48)	1.22 (0.52)	1.23(0.56)	1.24(0.61)	1.25(0.66)	1.26(0.71)	1.26(0.77)	1.27(0.83)	1.28(0.89)
Female locals(<60y)	2.88 (0.36)	2.91 (0.41)	2.93(0.48)	2.96(0.55)	2.99(0.63)	3.02(0.71)	3.04(0.81)	3.07(0.90)	3.10(1.01)
Male immigrants >10(<60y)	7.05 (1.11)	7.24 (1.32)	7.43(1.56)	7.62(1.84)	7.82(2.16)	8.01(2.50)	8.21(2.88)	8.40(3.30)	8.61(3.75)
Male immigrants ≤ 10(<60y)	2.01 (0.85)	1.95 (0.91)	1.9(0.94)	1.84(0.99)	1.79(1.04)	1.74(1.09)	1.69(1.14)	1.64(1.19)	1.60(1.24)
Male locals(<60y)	4.33 (0.48)	4.41 (0.57)	4.46(0.68)	4.53(0.81)	4.61(0.94)	4.69(1.09)	4.77(1.26)	4.85(1.44)	4.93(1.63)
Female immigrants >10(≥60y)	29.45 (2.11)	29.91 (2.54)	30.38 (3.06)	30.85 (3.66)	31.33 (4.33)	31.81 (5.08)	32.29 (5.91)	32.78 (6.79)	33.27 (7.74)
Female immigrants ≤ 10(≥60y)	15.65 (6.08)	15.49 (6.71)	15.33 (7.36)	15.16 (8.03)	14.97 (8.73)	14.79 (9.43)	14.59 (10.14)	14.39 (10.86)	14.19 (11.58)
Female locals(≥60y)	23.85 (4.46)	24.21 (4.81)	24.56 (5.23)	24.91 (5.73)	25.25 (6.30)	25.58 (6.95)	25.90 (7.67)	26.22 (8.47)	26.54 (9.34)
Male immigrants >10(≥60y)	44.36 (3.02)	45.85 (3.76)	47.41 (4.69)	49.04 (5.78)	50.73 (7.05)	52.48 (8.50)	54.28 (10.13)	56.16 (11.95)	58.11 (13.98)
Male immigrants ≤ 10(≥60y)	23.96 (9.01)	23.87 (9.74)	23.75 (10.52)	23.61 (11.33)	23.45 (12.17)	23.28 (13.04)	23.09 (13.93)	22.89 (14.83)	22.68 (15.75)
Male locals(≥60y)	31.17 (5.22)	31.55 (5.63)	31.93 (6.14)	32.30 (6.75)	32.66 (7.45)	33.01 (8.23)	33.35 (9.11)	33.69 (10.08)	34.03 (11.12)

eTable 4. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of pancreatic cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030.

Predictive mean of age-standardized mortality rates of stomach cancer per 100,000 population									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	7.95 (0.62)	7.71 (0.74)	7.47 (0.87)	7.25 (1.01)	7.03 (1.15)	6.83 (1.29)	6.62 (1.43)	6.43 (1.57)	6.24 (1.71)
Female immigrants ≤10	7.36 (1.56)	7.33 (1.69)	7.30 (1.85)	7.28 (2.01)	7.27 (2.20)	7.27 (2.40)	7.28 (2.61)	7.31 (2.84)	7.33 (3.09)
Female locals	4.91 (0.52)	4.75 (0.57)	4.61 (0.63)	4.47 (0.71)	4.34 (0.77)	4.21 (0.84)	4.08 (0.91)	3.95 (0.99)	3.83 (1.06)
Male immigrants >10	13.89 (0.97)	13.34(1.21)	12.81 (1.46)	12.31 (1.73)	11.83 (1.99)	11.38 (2.26)	10.95 (2.51)	10.54 (2.76)	10.15 (3.01)
Male immigrants ≤10	15.21 (3.38)	15.07 (3.67)	14.93 (3.98)	14.79 (4.31)	14.64 (4.65)	14.51 (5.02)	14.35 (5.39)	14.19 (5.78)	14.03 (6.17)
Male locals	8.07 (0.99)	7.73 (1.03)	7.41(1.07)	7.10 (1.13)	6.81 (1.19)	6.51 (1.26)	6.23 (1.33)	5.97 (1.39)	5.71 (1.46)
Female immigrants >10(<60y)	4.69 (0.79)	4.62 (0.87)	4.55 (0.96)	4.47 (1.07)	4.39 (1.17)	4.31 (1.29)	4.22 (1.41)	4.13 (1.52)	4.03 (1.64)
Female immigrants ≤ 10(<60y)	4.08 (0.93)	4.10 (1.03)	4.13 (1.14)	4.17 (1.27)	4.21 (1.41)	4.24 (1.55)	4.28 (1.70)	4.32 (1.87)	4.36 (2.05)
Female locals(<60y)	2.08 (0.27)	1.98 (0.29)	1.88 (0.32)	1.79 (0.35)	1.71 (0.37)	1.61 (0.41)	1.53 (0.43)	1.44 (0.45)	1.37 (0.47)
Male immigrants >10(<60y)	4.71 (0.79)	4.55 (0.89)	4.41 (0.99)	4.25 (1.10)	4.12 (1.21)	3.98 (1.32)	3.86 (1.43)	3.74 (1.54)	3.63 (1.65)
Male immigrants ≤ 10(<60y)	4.70 (1.42)	4.66 (1.55)	4.63 (1.69)	4.59 (1.83)	4.55 (1.99)	4.52 (2.15)	4.48 (2.32)	4.44 (2.50)	4.41 (2.68)
Male locals(<60y)	2.37 (0.29)	2.28 (0.32)	2.21 (0.35)	2.12 (0.38)	2.04 (0.42)	1.97 (0.45)	1.91 (0.49)	1.83 (0.52)	1.77(0.55)
Female immigrants >10(≥60y)	16.23 (1.26)	15.65 (1.47)	15.08 (1.70)	14.55 (1.94)	14.03 (2.18)	13.54 (2.43)	13.07 (2.68)	12.62 (2.92)	12.19 (3.16)
Female immigrants ≤ 10(≥60y)	13.01 (4.83)	12.52 (5.11)	12.03 (5.37)	11.55 (5.63)	11.08 (5.88)	10.63 (6.12)	10.19 (6.35)	9.76(6.56)	9.34 (6.75)
Female locals(≥60y)	11.86 (1.84)	11.67 (1.98)	11.49 (2.15)	11.33 (2.35)	11.18 (2.58)	11.04 (2.84)	10.91 (3.11)	10.79(3.4)	10.68 (3.71)
Male immigrants >10(≥ 60y)	36.59 (2.56)	35.17(3.18)	33.82 (3.86)	32.55 (4.57)	31.34 (5.28)	30.19 (6.01)	29.08 (6.70)	28.02 (7.40)	27.01 (8.07)
Male immigrants ≤10(≥ 60y)	41.43 (11.78)	41.03 (12.71)	40.61 (13.70)	40.17 (14.75)	39.71 (15.85)	39.24 (16.99)	38.75 (18.16)	38.23 (19.35)	37.71 (20.57)
Male locals(≥60y)	22.69 (3.56)	22.37(4.07)	22.16(4.84)	21.89 (5.86)	21.61 (7.22)	21.52 (9.02)	21.74 (11.29)	22.17 (14.03)	22.73 (17.28)

eTable 5. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of stomach cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030.

Predictive mean of age-standardized mortality rates of prostate cancer per 100,000 population									
Year	2022	2023	2024	2025	2026	2027	2028	2029	2030
Male immigrants >10	14.59 (0.79)	14.57 (0.96)	14.56 (1.15)	14.54 (1.37)	14.51 (1.61)	14.48 (1.86)	14.45 (2.13)	14.42 (2.42)	14.38 (2.72)
Male immigrants ≤ 10	8.78 (3.11)	8.58(3.29)	8.39 (3.49)	8.19(3.69)	8.10(3.89)	7.82(4.11)	7.63(4.31)	7.45(4.51)	7.27(4.72)
Male locals	9.66 (1.57)	9.67(1.66)	9.69 (1.77)	9.72(1.91)	9.75(2.06)	9.78(2.23)	9.82(2.43)	9.86(2.64)	9.9(2.88)
Male immigrants >10(<60 y)	0.52 (0.17)	0.51(0.19)	0.50 (0.21)	0.49(0.22)	0.48(0.24)	0.47(0.25)	0.46(0.27)	0.45(0.29)	0.44(0.31)
Male immigrants ≤ 10(<60y)	0.73 (0.77)	0.81(0.93)	0.87 (1.10)	0.94(1.31)	1.01(1.51)	1.09(1.75)	1.16(2.02)	1.24(2.32)	1.33(2.64)
Male locals(<60y)	0.66 (0.14)	0.66(0.16)	0.66 (0.19)	0.67(0.21)	0.67(0.24)	0.67(0.27)	0.68(0.31)	0.68(0.33)	0.69(0.37)
Male immigrants >10(≥ 60y)	49.61 (2.73)	49.63 (3.29)	49.64 (3.94)	49.64 (4.68)	49.64 (5.51)	49.63 (6.38)	49.62 (7.32)	49.61 (8.32)	49.58(9.37)
Male immigrants ≤ 10(≥60y)	27.66 (9.78)	26.53 (10.21)	25.4 (10.63)	24.28 (11.03)	23.16 (11.41)	22.07 (11.76)	21.01 (12.09)	19.96 (12.38)	18.95(12.63)
Male locals(≥60y)	31.48 (5.49)	31.40 (5.76)	31.32 (6.09)	31.24 (6.48)	31.15 (6.94)	31.06 (7.44)	30.96 (8.01)	30.86 (8.61)	30.74(9.26)

eTable 6. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of prostate cancer per 100,000 population for each age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030.

Reporting checklist for cohort study.

Based on the STROBE cohort guidelines.

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		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	5
Setting	#5	Describe the setting, locations, and relevant dates, including periods	5

		of recruitment, exposure, follow-up, and data collection	
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up.	5
Eligibility criteria	#6b	For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5
Bias	#9	Describe any efforts to address potential sources of bias	5
Study size	#10	Explain how the study size was arrived at	5
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	5
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	5
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	5
Statistical methods	#12c	Explain how missing data were addressed	5
Statistical methods	#12d	If applicable, explain how loss to follow-up was addressed	n/a
Statistical methods	#12e	Describe any sensitivity analyses	n/a
Results			
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible,	n/a

		included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	5
Participants	#13c	Consider use of a flow diagram	
n/a			
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	5
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	
n/a			
Descriptive data	#14c	Summarise follow-up time (eg, average and total amount)	
n/a			
Outcome data	#15	Report numbers of outcome events or summary measures over time. Give information separately for exposed and unexposed groups if applicable.	
n/a			
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6
Main results	#16b	Report category boundaries when continuous variables were categorized	n/a
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
n/a			
Other analyses	#17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	7

Discussion

Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	10
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

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An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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Abstract

Objectives: To explore the relationship between immigration groups and cancer mortality, this study aimed to explore age, period, birth cohort effects and effects across genders and immigration groups on mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers and their projections.

Design, Setting, and Participants: Death registry data in Hong Kong between 1998 and 2021, which were stratified by age, sex and immigration status. Immigration status was classified into three groups: locals born in Hong Kong, long-stay immigrants and short-stay immigrants.

Methods: Age-period-cohort analysis was used to examine age, period, and birth cohort effects for genders and immigration groups from 1998 to 2021. Bayesian age-period-cohort models were applied to predict the mortality rates from 2022 to 2030.

Results: Short-stay immigrants revealed pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Immigrants for each type of cancer and gender will be at a higher mortality risk than locals, as men will be at a higher risk of mortality from cancers than women in the future (excluding prostate cancer). After 2021, decreasing trends ($p<0.05$) or plateau ($p>0.05$) of forecasting mortality rates of cancers occur for all immigration groups, except for increasing trends for short-stay male immigrants with colon cancer ($p<0.05$, Avg +0.30 deaths/100,000 per annum from 15.47 to 18.50 deaths/100,000) and long-stay male immigrants with pancreatic cancer ($p<0.05$, Avg +0.72 deaths/100,000 per annum from 16.30 to 23.49 deaths/100,000).,

Conclusions: Findings underscore the effect of gender and immigration status in Hong Kong on mortality risks of cancers that immigrants for each type of cancer and gender will be at a higher mortality risk than locals.

Keywords: Age-period-cohort analysis, immigration, mortality, lung cancer, pancreatic cancer, colon cancer, liver cancer, prostate cancer, stomach cancer

Strengths and limitations of this study

- This study provides new evidence regarding the relationship between immigration status and cancer mortality, given the effects of age, period, birth cohort and their predictions.
- The non-identifiability problem has not been interpreted in APC models
- The future perspective of cancer therapies and techniques have not been considered.

Introduction

Several migration waves from mainland China to Hong Kong have occurred over the past century. These migration waves included a large-scale migration inflow from 1945 to 1950 (the Chinese Civil War) and a few small-scale inflows in the 1950s, 1970s, and 1990s [1-3]. In 2016, immigrants from mainland China formed approximately 38% of the population of Hong Kong. These inflows have led to a growing interest in research on the disparity of health conditions between the locals and immigrants.

Cancer has been one of the most common causes of death, as an estimated 19.3 million new cancer cases and 9.9 million new cancer-associated deaths occurred worldwide in 2020 [4]. In Hong Kong, lung cancer is one of the most common causes of cancer deaths [5, 6]. Previous studies suggested that the primary cause of lung cancer is cigarette smoking [7-11]. Genetic factors, asbestos, radon gas, second-hand smoke, and other forms of air pollution have been proven to influence the risk of lung cancer [12-18]. The overall daily smoking rate in mainland China was approximately 23.2% in 2018 [19], whereas the daily smoking rate in Hong Kong was only 10.2% in 2019 [20]. The leading causes of liver cancer include viral infection, drinking of alcohol and polluted water and food supplies which are also culprits for colon, stomach and pancreatic cancer [21]. Alcohol consumption per capita in Hong Kong has reached 2.37 liters in 2021 [22], compared to 7.0 liters of per capita consumption of alcohol in mainland China in 2018 [23]. As approximately 99% of prostate cancer cases occur after age 50, factors of prostate cancer have been regarded as old age, race, family history and the diet of red meat consumption [24]. In addition to these risk factors, studies have suggested that cancer mortality rates vary depending on migrant status [25-28]. According to data from the Census and Statistics Department of Hong Kong, approximately 81% of immigrants in Hong Kong immigrated from mainland China, Macau, and Taiwan. Immigrants from mainland China account for the bulk of this population. Previous studies have shown that child immigrants in Hong Kong tend to suffer from a higher risk of wheezing disorders and cardiovascular diseases, and immigrant women have higher age-specific mortality rates of breast cancer than locally-born women in Hong Kong [29, 30]. However, to date, few studies have investigated the effect of length of stay in Hong Kong and birthplace on the risk of other types of cancer.

In this study, we compared the mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers between locally born residents in Hong Kong and immigrants from mainland China. Both populations are widely considered as ethnically homogeneous with similar cultures. Nevertheless, due to different early life experiences, immigrants are exposed to more various social economy and lifestyles than locals. Therefore, it's constructive to ascertain whether immigrants from mainland China have a different mortality pattern of cancers from locals to

verify the significance of migration status for this health outcome. As Age-period-cohort (APC) analysis plays a vital role in studying time-specific phenomena in epidemiology, in this study, to evaluate the effect of immigration on cancer mortality in the past and future, we developed APC models specified by sex and migrant status to assess the effects of age, period, birth cohort, and of the length of stay in Hong Kong on the mortality risks of cancers. Additionally, we explore the projection of mortality rates for the locally born population and immigrants in Hong Kong who were younger or older than 60 using a predictive model, taking into account age, period, and birth cohort effects as well.

Methods

Data

We obtained the death registry data in Hong Kong between 1998 and 2021 from the Census and Statistics Department of Hong Kong, as the data in 2022 has not been available up to now. The data was extracted from a routine census held by the Hong Kong government as subjective errors caused by resampling can be neglected. The population data were stratified by age, sex, immigration status, and length of stay in Hong Kong. We retrieved six types of cancer cases from the death registry data using ICD codes, such as ICD-9 code 162 and ICD-10 codes C34.0–C34.3, C348, and C349 for lung cancer. To assure comparability among registries, deaths from the age group of 35–85 years were selected, since cases younger than 35 and older than 85 were relatively trivial for lack of statistical interpretability [31]. Immigration status was classified into three groups: locals born in Hong Kong, immigrants who have lived in Hong Kong for >10 years before death defined as long-stay immigrants, and immigrants who have lived in Hong Kong for ≤10 years before death defined as short-stay immigrants. Notably, much focus was placed on immigrants from mainland China, because approximately 81% of immigrants in Hong Kong came from mainland China, Macau, and Taiwan based on the data from the Census and Statistics Department of Hong Kong. Moreover, few cases recorded from Macau and Taiwan are statistically insignificant in the analysis. Demographics and population projections from 2022 to 2030 were retrieved from the Census and Statistics Department of Hong Kong and estimated with cubic smoothing spline as the prerequisite of the predictive model. Codes for APC and BAPC analysis are available in the GitHub repository (https://github.com/kshz2164313/APC-population-projections-for-immigration-HK).

Statistical analysis

We modeled cancer mortality rates in Hong Kong using APC analysis based on log-linear Poisson regression models. The model aimed to disentangle age, period, and cohort effects of time-varying phenomena simultaneously [32, 33], given that

$$\log(E_{ij}) = \alpha_i + \beta_j + \gamma_k + \mu + \log(\theta_{ij}) \quad (1)$$

where E_{ij} denotes expected mortality; α_i, β_j, and γ_k denote age, period, and cohort effect, respectively, for $i = 1,...,I$, $j = 1,...,J$, $k = 1,...,K$ with $k = I - i + j$. $\log(\theta_{ij})$ is the offset. We mainly focused on the contributions of sex and immigration status due to the non-identifiability problem that the effects of these three components are collinear with each other (denoted as period – age = cohort) [34]. Birth cohort effect and period effect were assessed with relative risks to evaluate the effect of three components. The median year of birth among cases was regarded as the reference cohort [35,36]. Since death cases aged at 35–85 years between 1998 and 2021 were selected, the range of birth cohort from 1913 to 1986 covered observations and further projections until 2030. The second and penultimate period effects were constrained to the reference for period. For sex and immigration status, maximum likelihood framework was applied to estimate the relative risks and 95% confidence intervals (CIs) by age groups, calendar period, and birth cohort.

Several projection approaches for future cancer mortality have been developed, but a Bayesian age-period-cohort (BAPC) model built upon integrated nested Laplace approximations (INLA) [37] yields relatively higher coverage and better performance for all evaluated parameter combinations [38]. To prevent some sampling problems caused by Markov chain Monte Carlo (MCMC), this MCMC-free BAPC approach was applied to predict future cancer mortality within a fully Bayesian inference setting and provide outputs of interest simply, such as projected age-standardized and age-specific rates. Convergence checks are not necessary for this technique [37]. The projections of age-standardized cancer mortality rates for each sex, age group (younger or older than 60 years) and migrant status, taking into account age, period, and birth cohort effects, were performed based on the weights of population age groups from the WHO World Standard population [39], with 95% prediction intervals. Mann-Kendall trend test was applied to verify the projection trend.

All analyses were performed via R version 4.2.1 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria, 2013, http://www.R-project.org/). The APC models were established using the Epi package, and the projections based on Bayesian APC models were performed with the BAPC package.

Patient and Public Involvement

None.

Results

Figure 1 & 2 and eFigure 1(a-e) in **Supplementary Material** illustrate the estimates of age

(assessed by cancer mortality), cohort and period effects (assessed by relative risk) based on APC models among three migrant groups for men and women with six types of cancers, respectively. All the mortality rates for each gender and immigration status exhibit notable increasing trends with age. Age, cohort and period effects of six types of cancer for immigrants who stayed in Hong Kong for ≤10 years revealed relatively more pronounced fluctuations and deviations from those effects in the other two immigration groups. Significant increasing trends of age effect occurred in all types of cancer, regardless of gender and immigration status. For example, while relatively insignificant differences in lung cancer mortality rates by immigration status among females have performed, male immigrants who remained in Hong Kong for >10 years had higher lung cancer mortality rates at ages above 50 years and those who arrived ≤10 years had lower lung cancer mortality at ages below 62 years compared to local men Figure 1. In addition to compatible dynamics of period effect for locals and long-stay immigrants, similar changes of relative risks by birth cohort for locals and long-stay immigrants in lung, colon, liver and stomach cancers occurred before 1945, whereas significant differences of relative risks by birth cohort between these two immigration groups occurred after 1960 (Figure 1 & eFigure 1(a,b,d)). Locals and long-stay immigrants in pancreatic and prostate cancer perform almost similar changes of relative risks by birth cohort effects all the time (eFigure 1(c,e)). Short-stay immigrants who have stayed in Hong Kong for ≤10 years had more fluctuating relative risks affected by period effects before 2020 than those for locals and long-stay immigrants. Lack of young cases, especially young short-stay immigrants, of prostate cancer leads to significant deviations and variances in age and cohort effects.

Figure 3-5, eFigure 2-6 in **Supplementary Material** illustrate the age-standardized mortality rates of six types of cancer from 1998 to 2021 and their projections by sex, immigrant status and age groups from 2022 to 2030, taking into account age, period, and birth cohort effects. Means and standard deviations of predictive mortality rates are shown in eTable 1-6 in **Supplementary Material**. For all ages projection (Figure 2 & eFigure 2-6), as men will be at higher risk of mortality rates of cancers (excluding prostate cancer) than women in the future for all three age groups (all ages, young and older than 60 years), given the projected trends, immigrants for each gender, especially who have stayed in Hong Kong for > 10 years will suffer from higher mortality rates of cancer in each year than locals. Monotone decreasing trends or plateau of forecasting occur for both genders and all immigration groups in cancers, except for increasing trends for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer ($p < 0.05$, Avg +0.30 deaths/100,000 per annum) from 15.47 deaths/100,000 (95% CI: 11.28, 19.66) in 2021 to 18.50 deaths/100,000 (95% CI: 2.31, 34.69) in 2030, and male immigrants who have stayed in Hong Kong for > 10 years with pancreatic cancer ($p < 0.05$, Avg +0.72 deaths/100,000 per annum) from 16.30 deaths/100,000 (95% CI: 14.38,17.26) in 2021 to 23.49 deaths/100,000 (95% CI: 12.49, 34.49) in 2030. Most of predictive trends for

younger cases (<60 years) and older cases (≥60 years) reach a consensus with those for all ages population, except for two phenomena: 1.) mortality rates of lung cancer for men immigrants ≤10 that insignificant trend for all ages ($p > 0.05$) vs. decline for younger cases ($p < 0.05$) vs. increase for older cases ($p < 0.05$); 2.) mortality rates of liver cancer for men immigrants >10 that decline for all ages ($p < 0.05$) vs. decline for younger cases ($p < 0.05$) vs. insignificant trend for older cases ($p > 0.05$). Some particular cases occur in the projection of prostate cancer that young long-stay male immigrants (0.44 deaths/100,000, 95% CI: 0, 1.05) aged less than 60 will be at lower mortality rate than locals (0.69 deaths/100,000, 95% CI: 0, 1.42) in 2030 (eTable 6). Compared with other cancers and immigration groups, male immigrants who have stayed in Hong Kong for >10 years with lung cancer would perform the most significant decline in predictive mean from 102.90 (95% CI: 98.14, 107.66) to 79.55 (95% CI: 47.46, 111.64) deaths per 100,000 population (Avg -2.34 deaths/100,000 per annum) (eTable 1), while the same immigration group with pancreatic cancer would indicate the most significant uptrend in each year of 16.30 (95% CI: 14.38,17.26) and 23.49 (95% CI: 12.49, 34.49) deaths per 100,000 population in 2021 and 2030, respectively (Avg +0.72 deaths/100,000 per annum) (eTable 4).

Discussion

Early detection of cancer is positive and instructive for increasing chances of cure. Nevertheless, the high mortality rate of cancer results from late diagnosis among most patients after progression to more advanced or severe stages. Individuals at high risk of cancer, such as smokers, alcoholics or those who are frequently exposed to susceptible circumstances, should be screened for early detections to increase opportunities for cure [40]. Therefore, the differences in mortality rates among immigration groups are synonymous with detection means, therapies, and social history in disparate periods and areas.

While the changes in mortality rates by age for long-stay immigrants reached approximate harmony with those for locals, the changes in mortality rates by age for short-stay immigrants revealed clear differences with those for the other two populations. The group of long-stay immigrants had a higher risk of death from lung, colon and liver cancers than the other two immigration groups after the age of 60 years. Short-stay male immigrants were less likely to die from lung cancer before the age of 65 years. The contrast in age effects among the immigration groups was partially consistent with studies [25, 41] that highlighted the age effects for locals and immigrants on breast cancer mortality in Hong Kong and lung cancer incidence in Sweden, as they both showed similar trends and magnitudes between locals and immigrants before the age of 60 years. They are also compatible with the results in [42] that

diagnosis of liver cancer is the most frequent among populations at 55 to 65 years old. According to these trends, young individuals, especially new young immigrant men, who have benefited from all-rounded development in mainland China and Hong Kong, are more likely to seek early detection and be treated for cancers using more advanced treatments [43]. Differences in birth cohort effects among immigrant groups partially comply with the interpretation above.

We observed significant trends of cohort effects among locals and immigrants. These findings are partially consistent but subtly different from previous findings, regarding the effect of immigration status on cancers. Zhao et al. [25] described multiple peaks of cohort effects on breast cancer mortality between locals and immigrants in Hong Kong, as well as a significant decline in cohort effects after 1950. In contrast, Sung et al. [44] investigated the difference in breast cancer incidence between Chinese Americans and non-Hispanic whites in the U.S. and emphasized that Chinese Americans were at lower risk of breast cancer than non-Hispanic whites born in the same year. Here, we interpret the cohort-driven trends resulting from the intricacy of social history and lifestyle. Compared to a relatively stable social development in Hong Kong, representing downward trends of relative risks for locals, wars and social instability in mainland China resulted in several immigration waves from mainland China to Hong Kong before 1950. Additionally, remarkable increasing trends were recorded for new immigrants after 1950, which corresponded to the economic downturn after wars and famine between 1959 and 1961 during their youth [45]. The increasing trends for new immigrants and similar trends for locals and long-stay immigrants were consistent with the finding that nutrient deficiency contributes to a higher risk of severe mortality rates of cancers [46]. Furthermore, we speculate that these trends, especially those for locals and long-stay immigrants, are most likely attributed to social development and personal behaviors, such as daily habits, occupational history, different diagnoses and treatments, and domestic environmental exposures. Notably, short-stay immigrants suffered from a lower risk of death from colon cancer for all ages (eFigure 1a in **Supplementary Material**). As locals and immigrants in Hong Kong transitioned to more westernized lifestyles, higher consumption of meat was associated with a higher risk of these types of cancer, whereas consumption of vegetables had a strong protective effect against pancreatic cancer, and moderate consumption of coffee appeared to be beneficial against lung cancer [47,48]. Further studies on potential risk factors are required.

Short-stay immigrants had more fluctuating and non-stationary but inconspicuous relative risks by period effects before 2021 than locals and long-stay immigrants. Cumulatively, an arch pattern and fluctuating curve depicting period effects externally resulted in an arch pattern of age-standardized mortality rates for short-stay immigrant women and irregular rates

for short-stay immigrant men before 2021. The external performance of different period effects on mortality rates could be most likely attributed to the higher effect of different lifestyles and social development on new immigrants than on long-stay immigrants and locals in Hong Kong. For the age-standardized mortality rates and projections, consistent with previous findings [49,50], we predict that the mortality rates of cancer in Hong Kong after 2021 will continue to decline or remain relatively stable, consistent with the trends before 2020, except for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer. Men will be at higher risk of mortality rates of cancer than women, regardless of immigration status. They are also compatible with the results in [4] that men suffer from a higher risk of these types of cancer than women, excluding prostate cancer. Furthermore, new immigrant women will be at lower risk than local women, even though long-stay immigrants will suffer from higher mortality rates than locals in the future. Potential interpretations could be consistent with those for birth cohort effects, as age and period effects are considered as confounders of cohort effect.

In the past few decades, spurred by an increasing burden of high incidence and mortality rates of cancer, several studies focused on the inherent identification dilemma of three effects in the APC model. Further, complicated population distribution and immigration status in Hong Kong, one of the areas with the highest population density and migration frequency in the world, have intricate causes and inherent dynamics of cancer and other diseases. To our knowledge, few studies have assessed the relationship between immigration status and cancer mortality. Therefore, this study is original to examine the effect of the length of stay in Hong Kong and origins of previous residence on cancer deaths, which is instructive for further immigration policy-making and targeted strategies of disease detection and intervention. However, this study had several limitations. Given the non-identifiability problem in age-period-cohort models, we could only depict trends and variations among different immigration and sex groups, as illustrated in figures, and insufficiently perform the estimates of the contributions of three effects or subgroups to mortality rates. Furthermore, we adopted a cubic smoothing spline to estimate populations of immigrants and locals due to the large proportion of unspecified immigration status from official demographic projections. A few acceptable cases resulted in a limited type of cancer so that some common cancers, such as the ovary and cervix, were discarded. Since the issue of quantification, the future perspective of cancer therapies and techniques have not been considered in the model of projection.

Conclusion

We conclude that immigrants, especially short-stay immigrants, had more pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Men will be at a higher risk of mortality rates of six types of cancer than women in the future. Male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer would perform significant uptrend in the future, while other immigration groups for each type of cancer would continue to decline or remain relatively stable. Immigrants for each gender in Hong Kong would suffer from higher mortality risks of cancers than locals in the future.

Declaration

Ethical approval and consent to participate

Ethical approval and consent to participate are not applicable. This study does not involve human participants. Data was obtained from the Census and Statistics Department of Hong Kong.

Consent for publication

Not applicable.

Data Availability Statement

Data are available upon reasonable request.

Author contributions

Yanji Zhao: Methodology, Formal analysis, Data Curation, Writing - Original Draft, Visualization
Zian Zhuang: Methodology, Formal analysis, Data Curation, Writing - Review & Editing
Lin Yang: Validation, Writing - Review & Editing
Daihai He: Conceptualization, Writing - Review & Editing, Supervision

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Conflict of interest

None declared.

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None.

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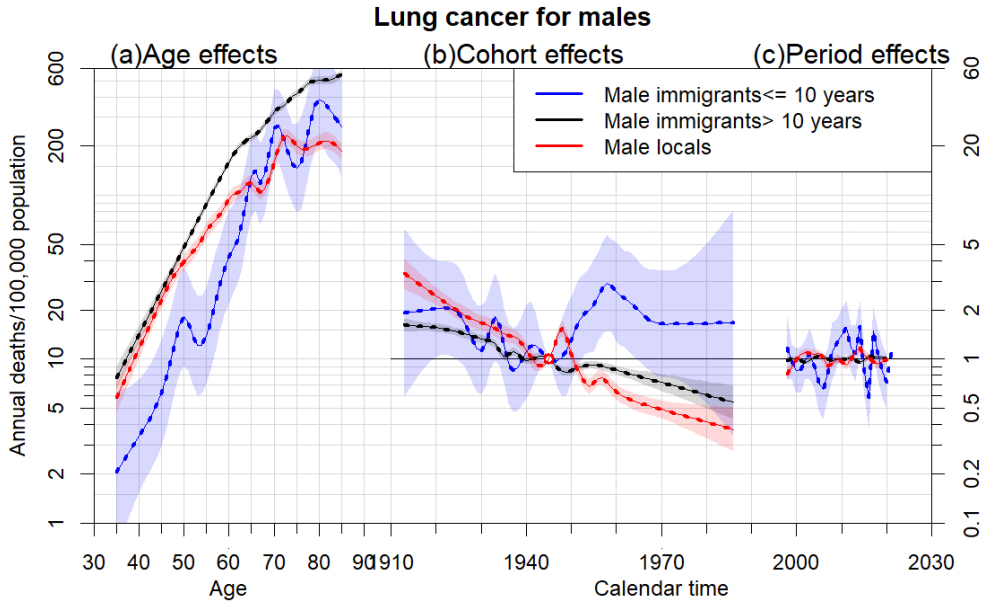
Figure 1. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

Figure 2. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of female lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

Figure 3. Projections of lung cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 4. Projections of lung cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 5. Projections of lung cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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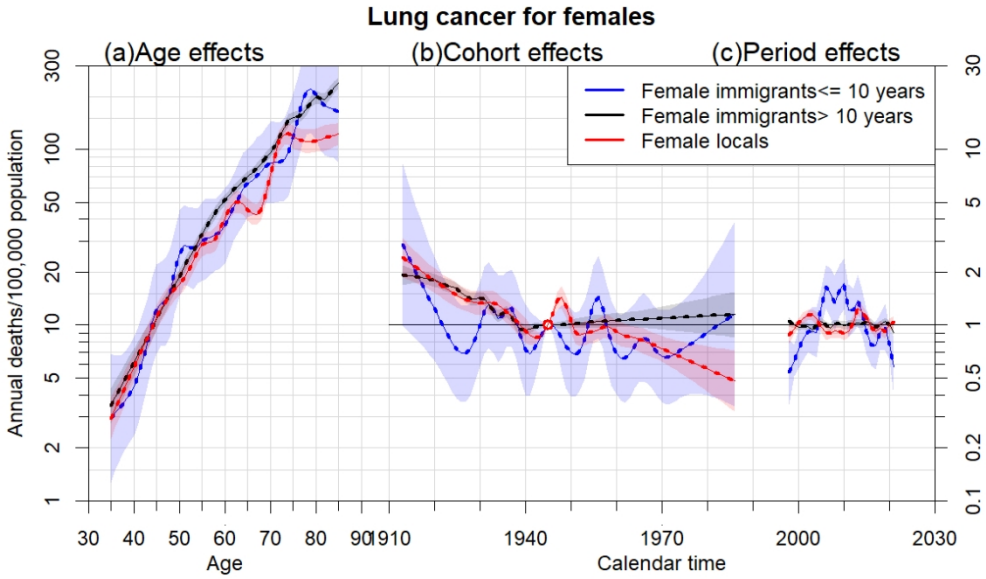

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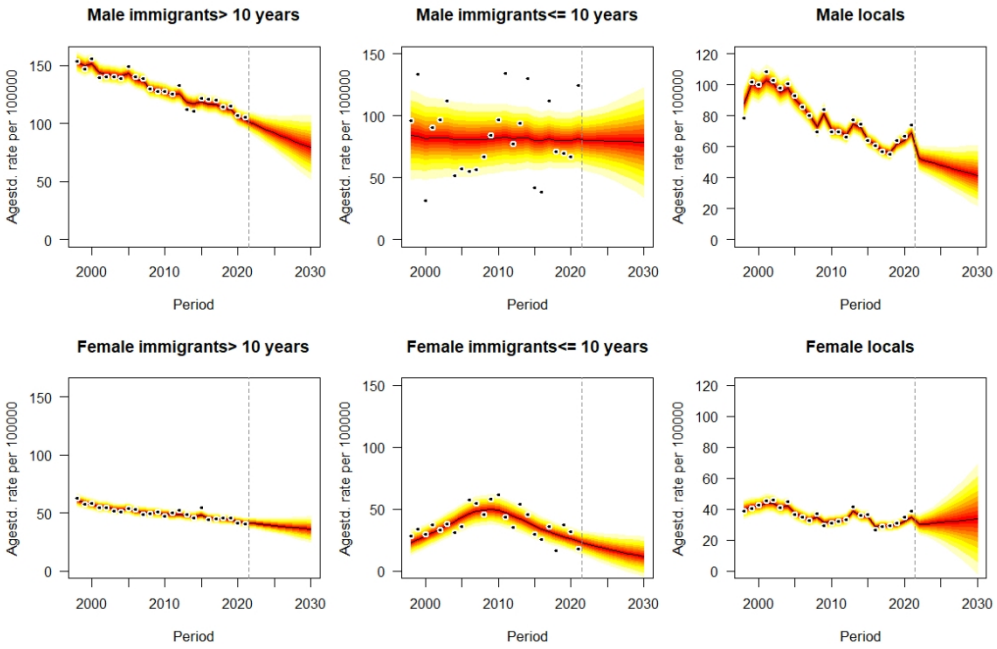

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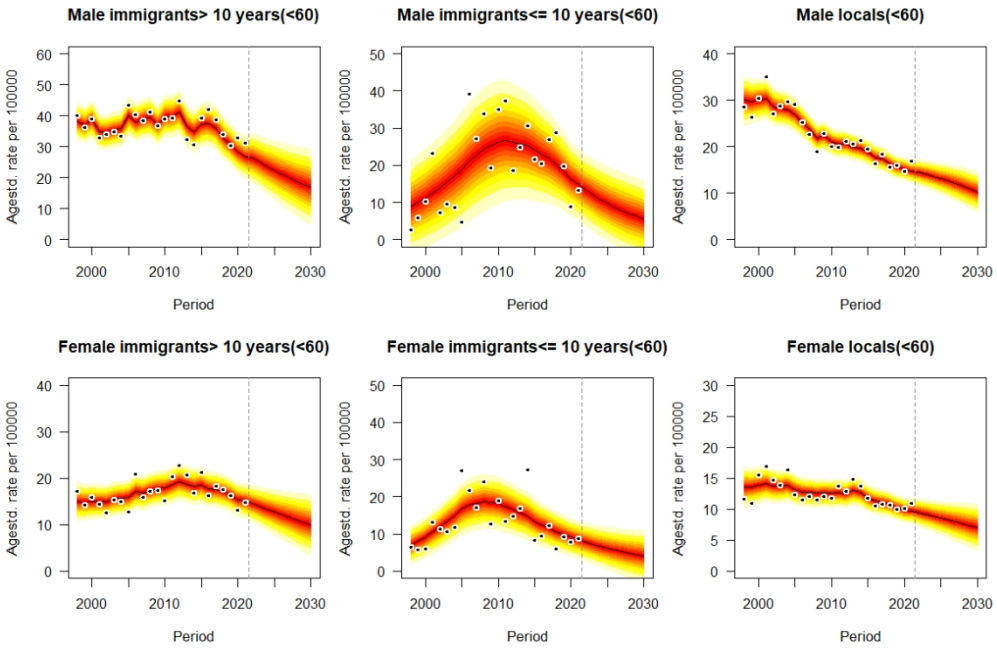

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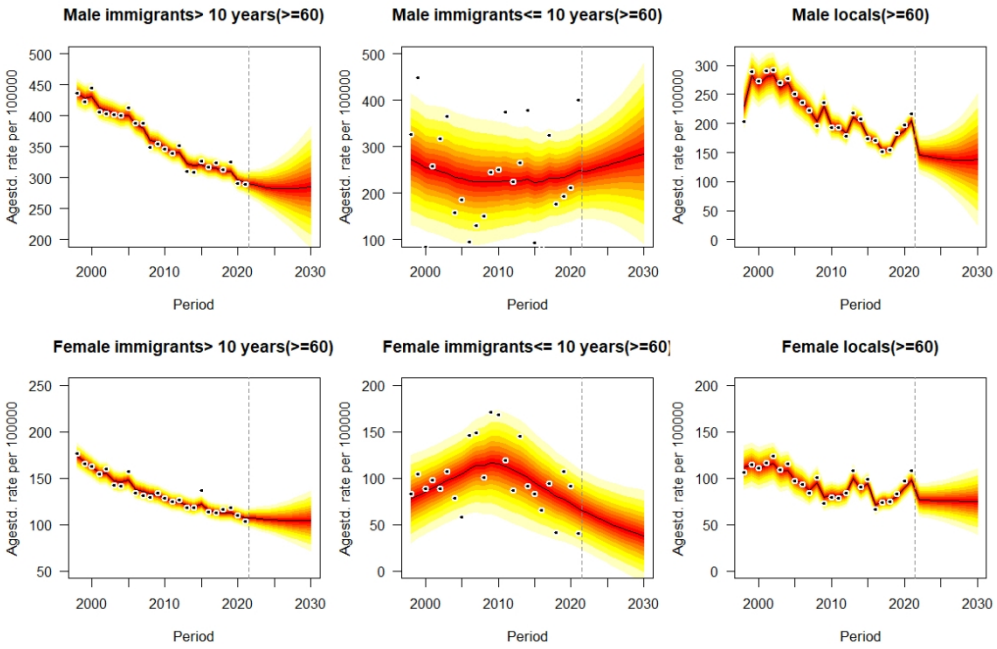

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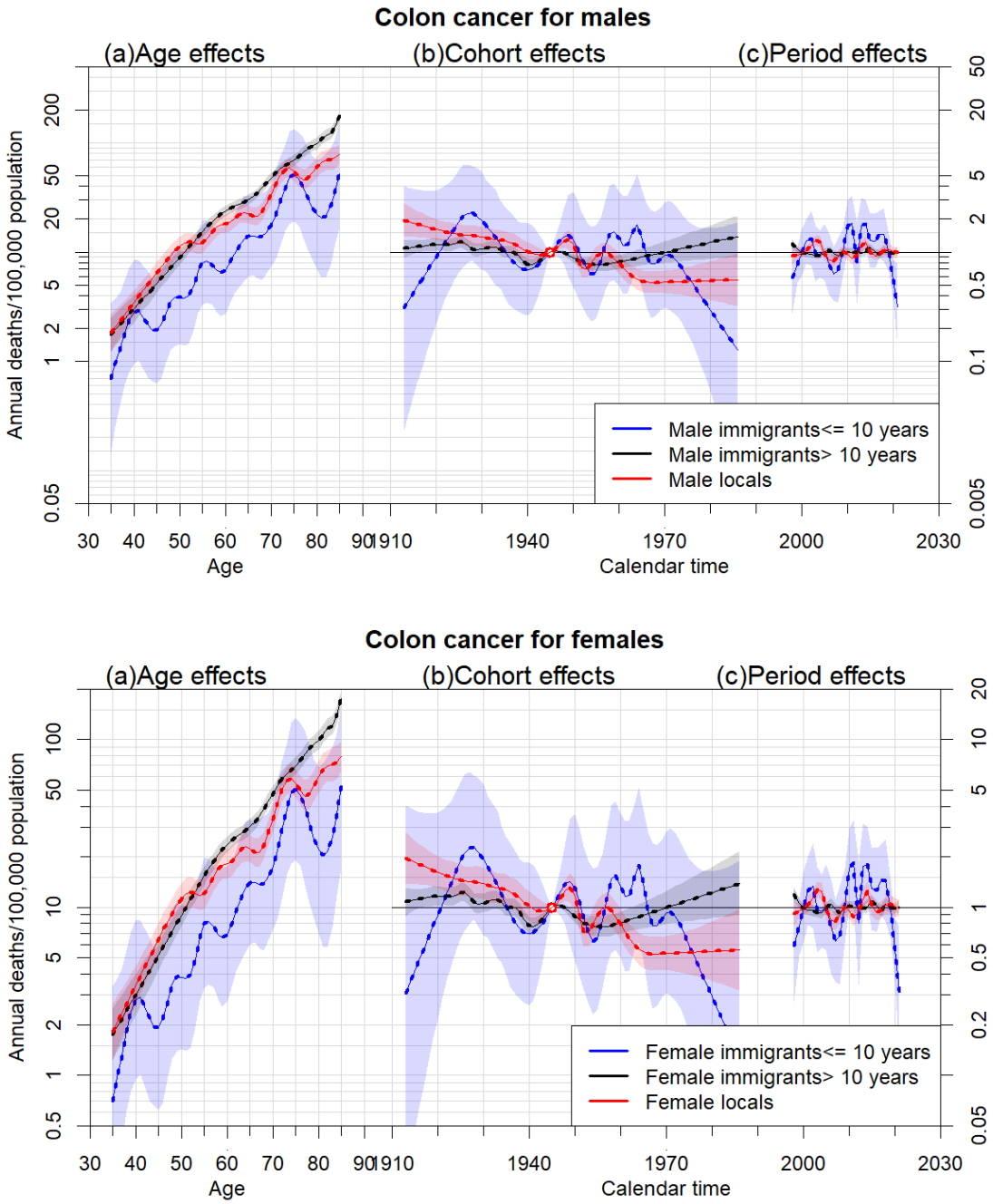
Supplementary Material for

"An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030"

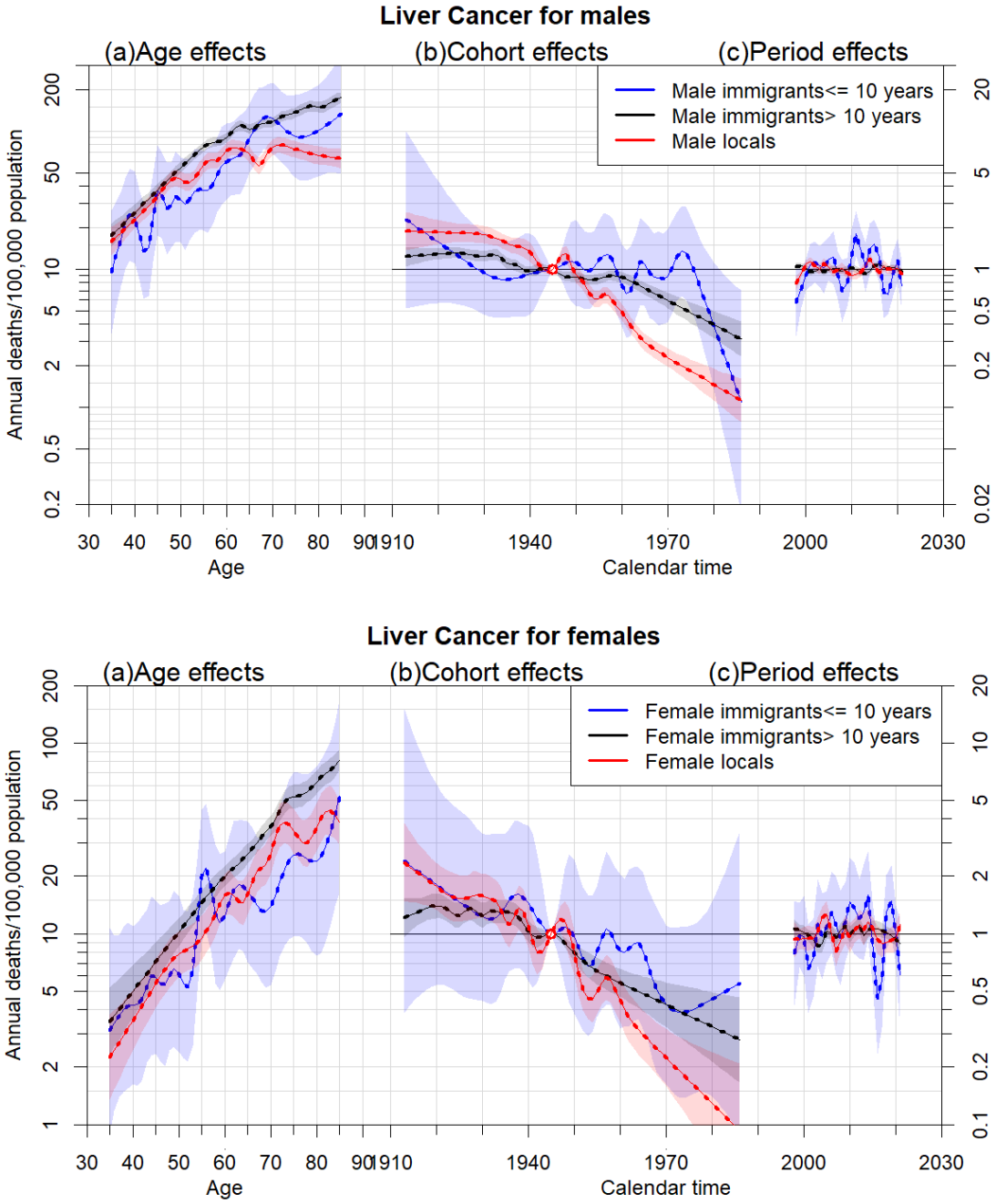
APC Figures

Projection Figures

Tables



eFigure 1(a). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female colon cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



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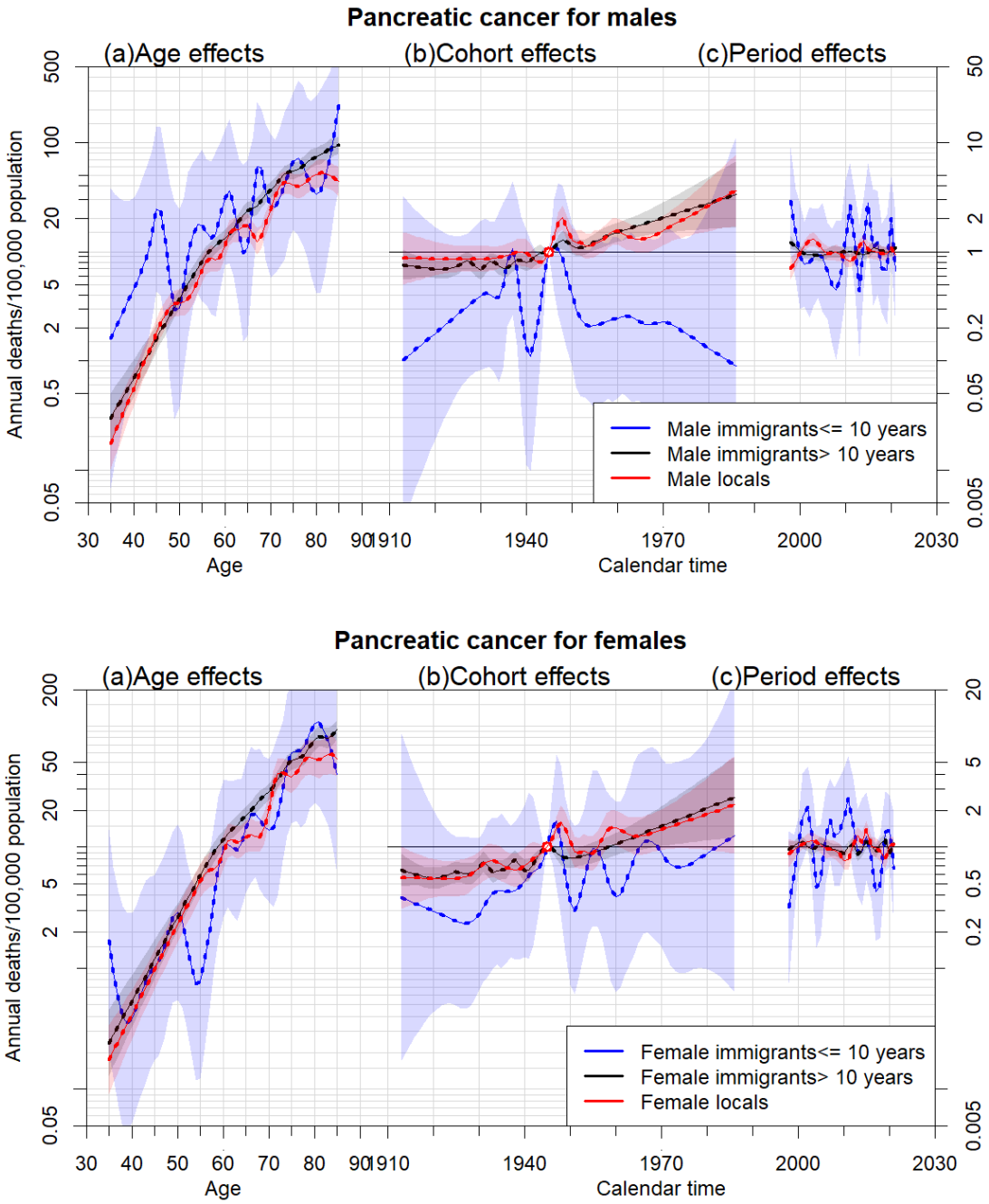
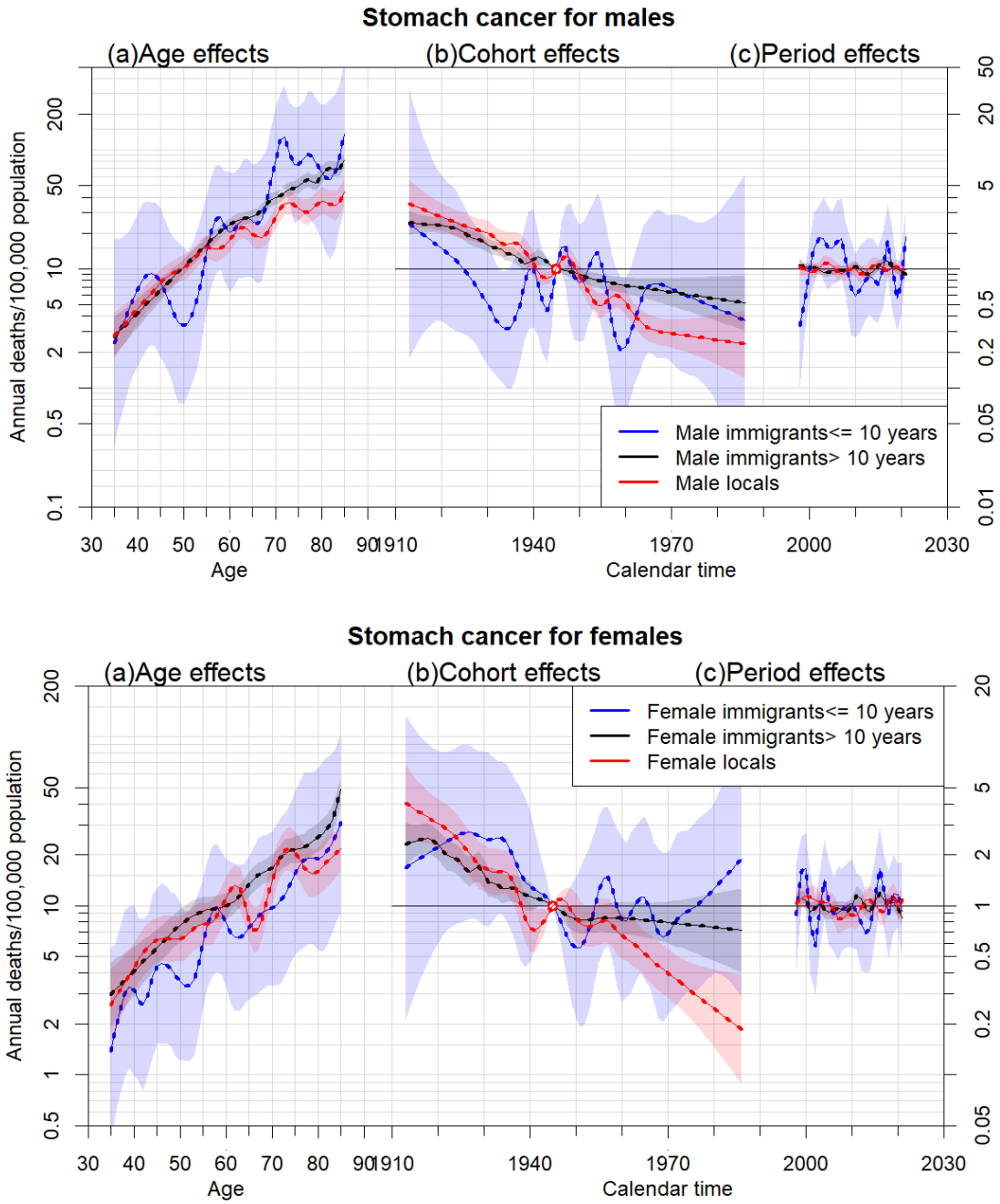


eFigure 1(c). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female pancreatic cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



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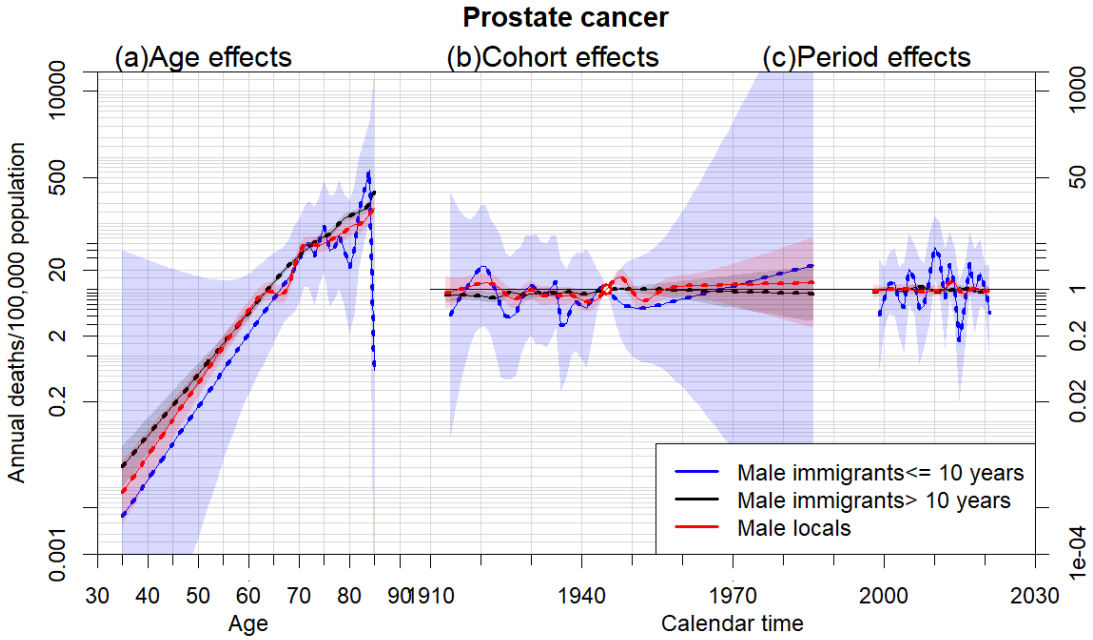

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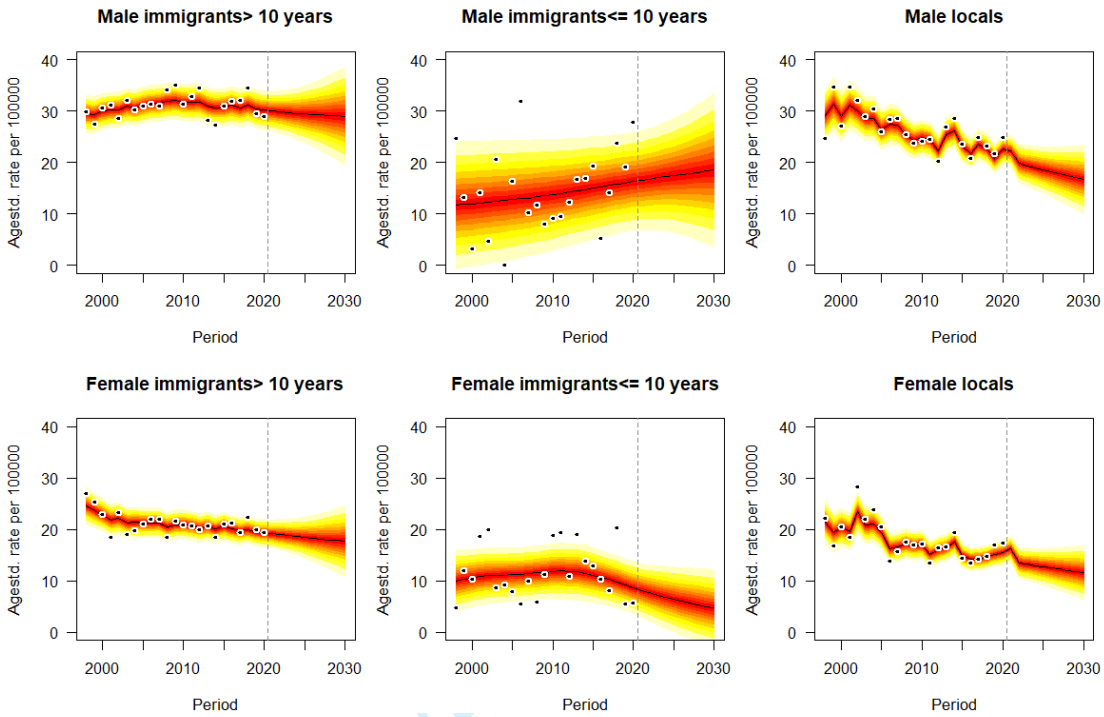

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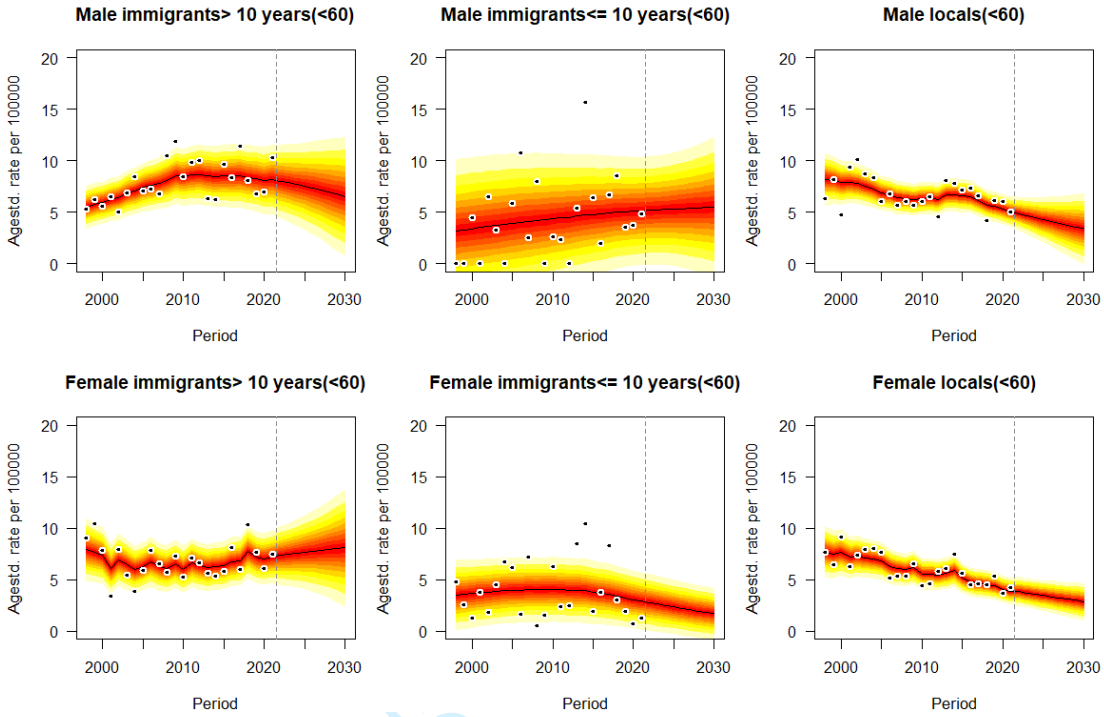

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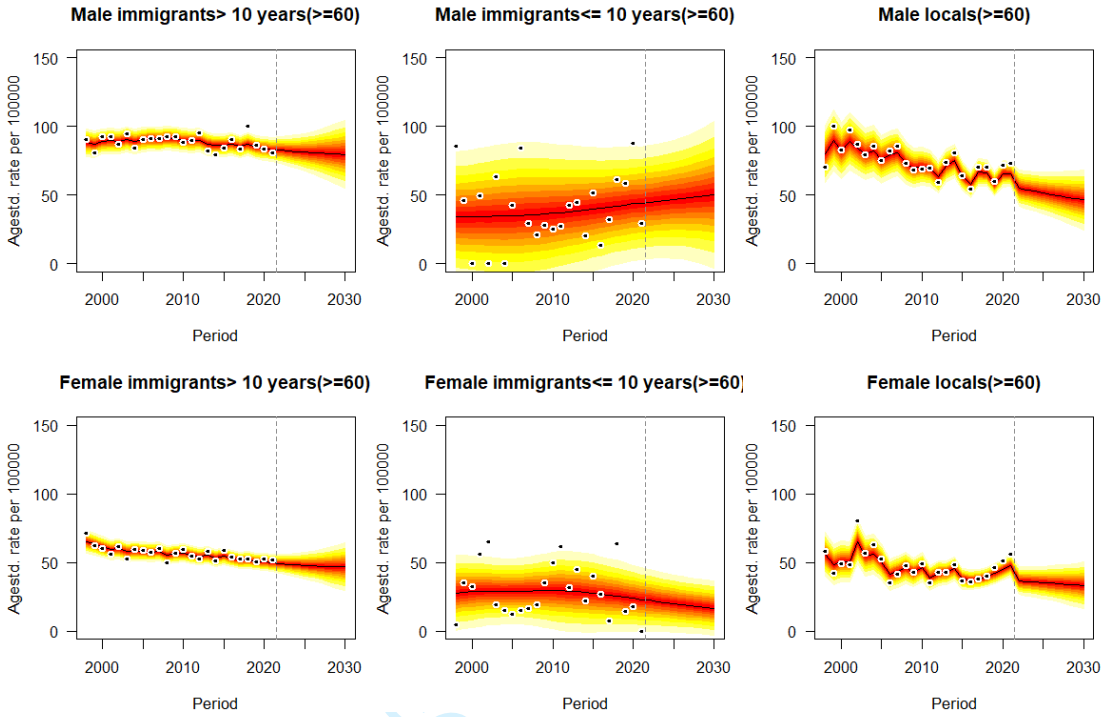
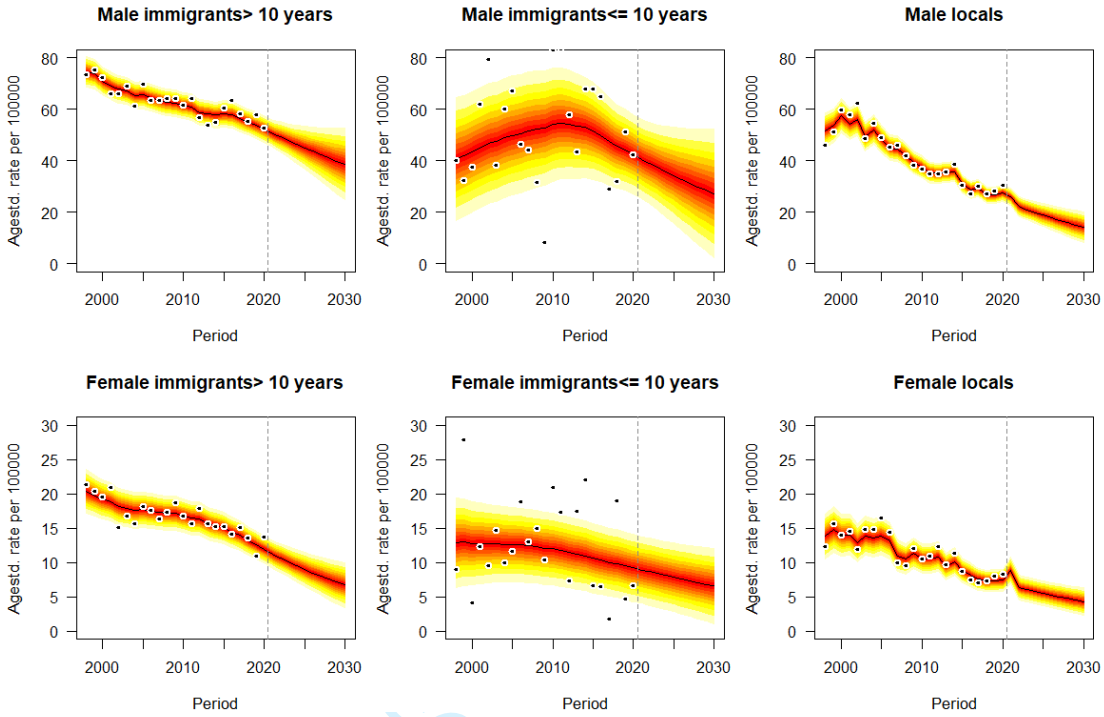


eFigure 2(c). Projections of colon cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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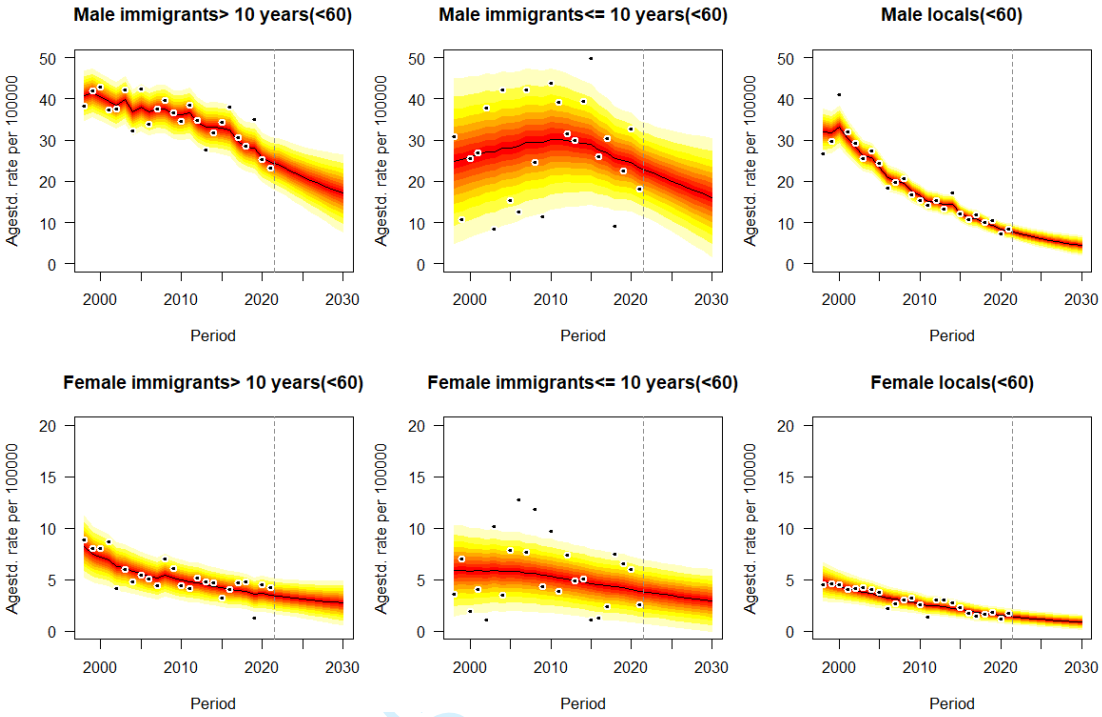

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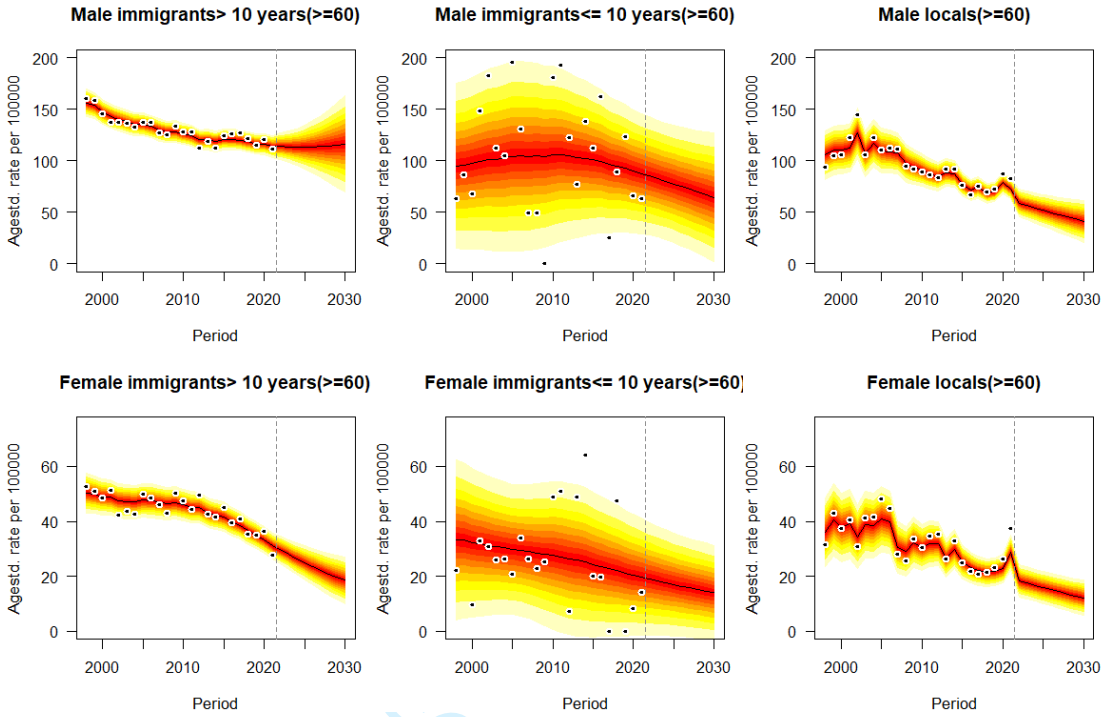

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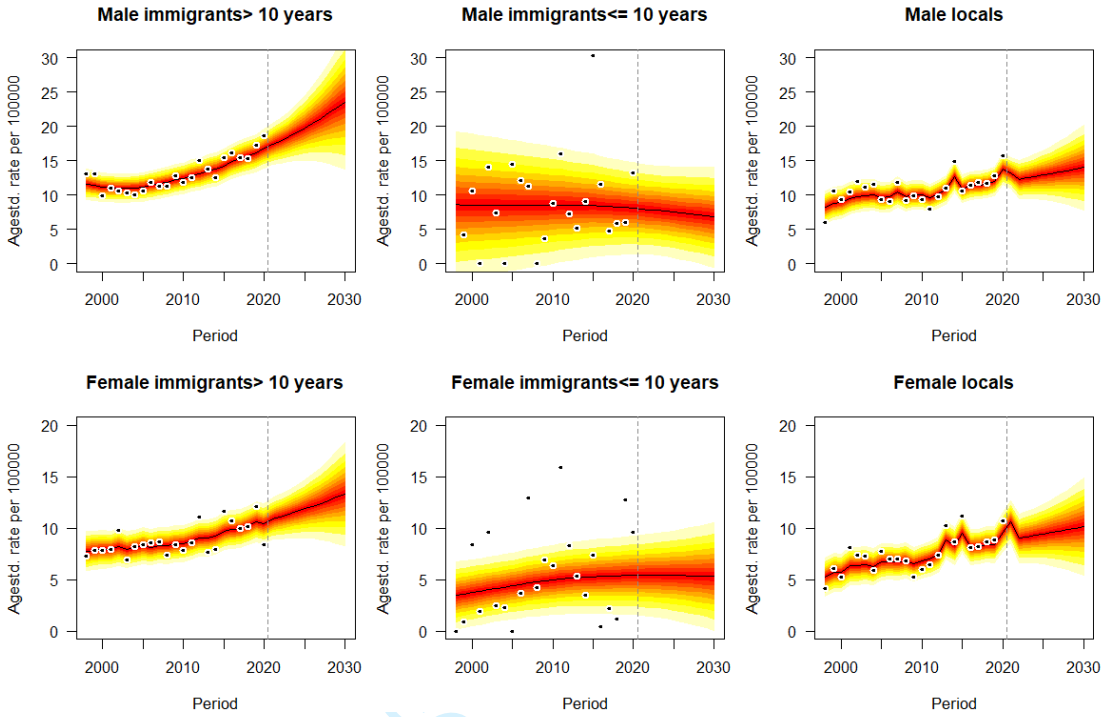

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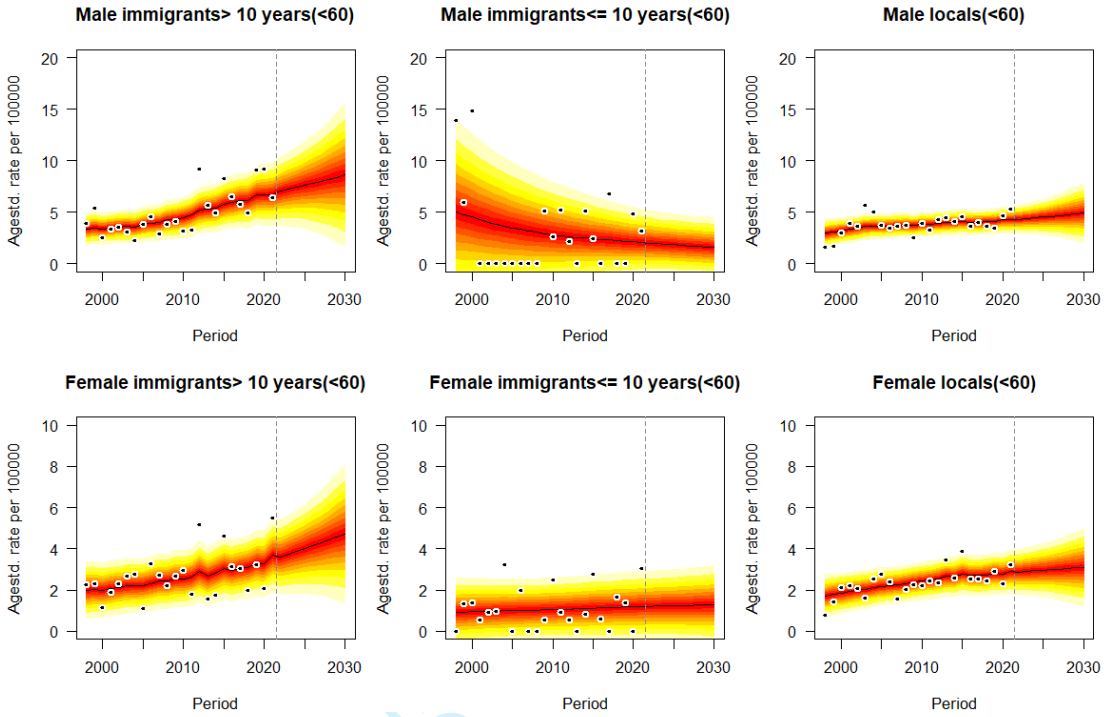

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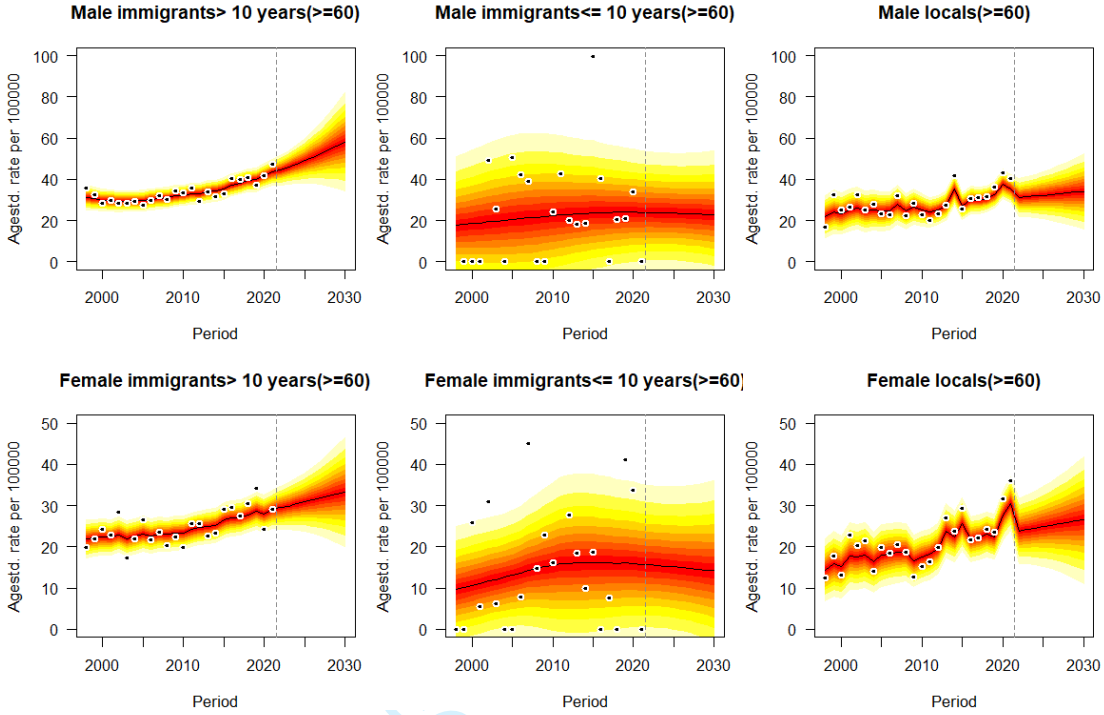
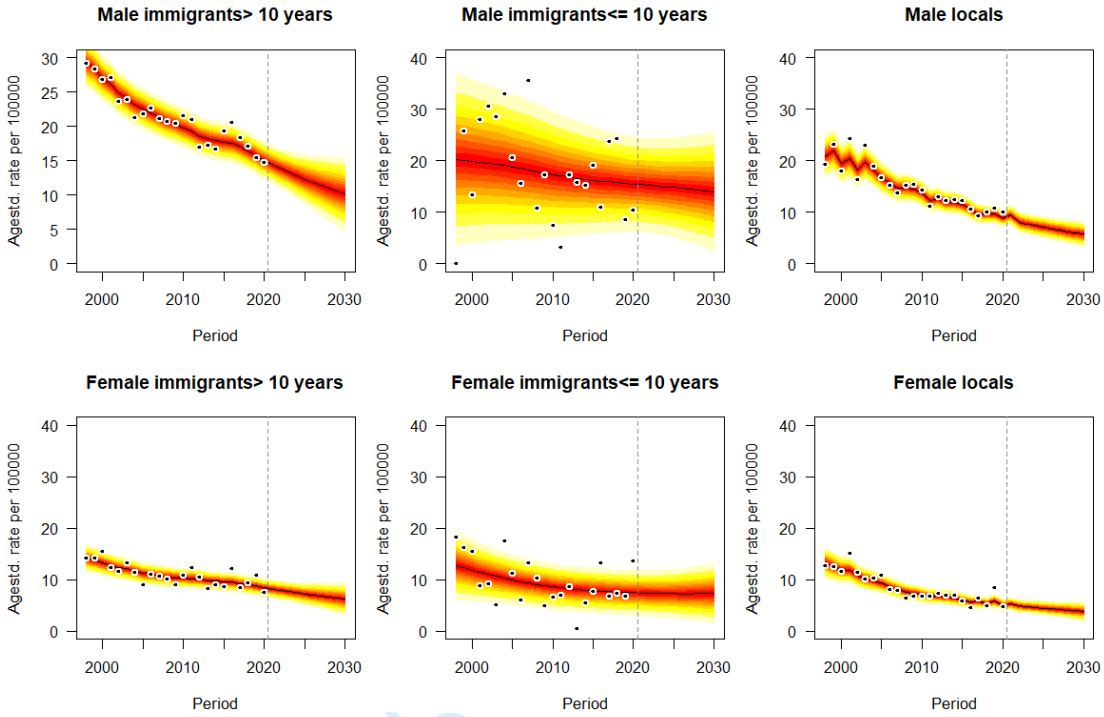
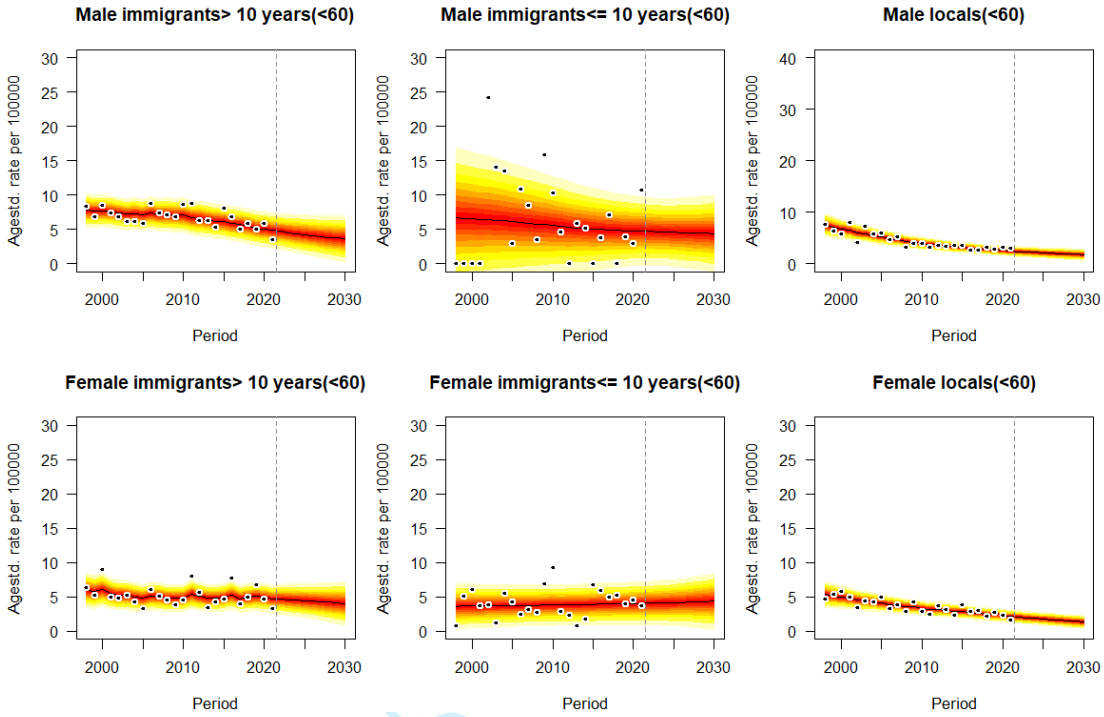


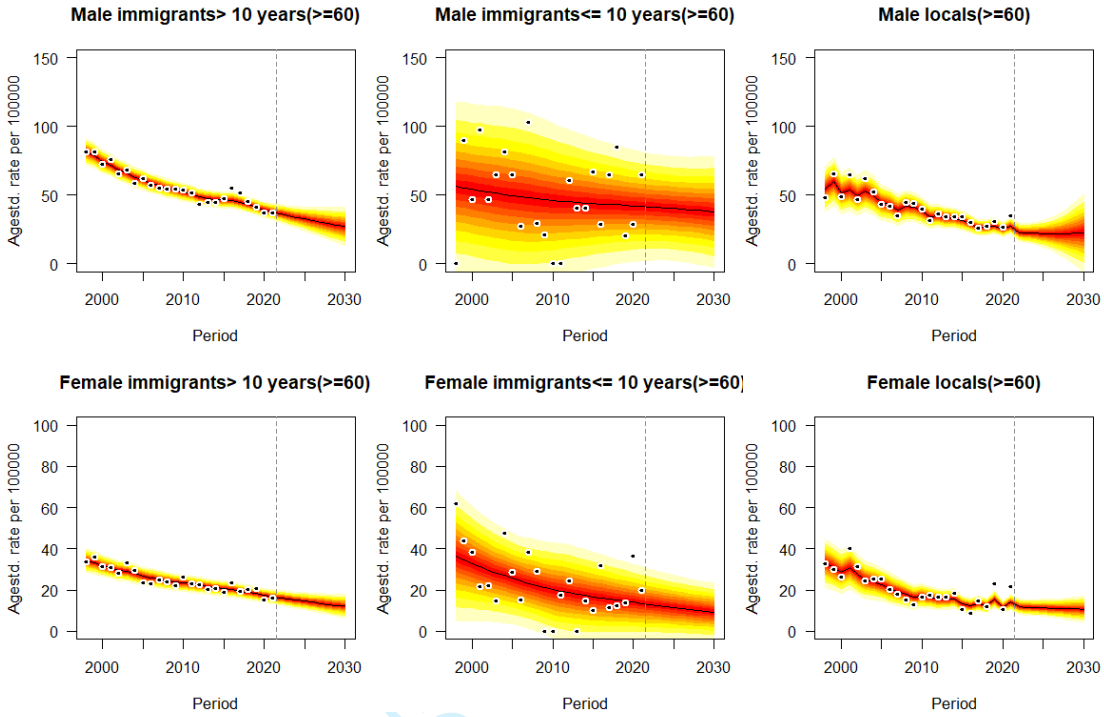
eFigure 4(c). Projections of pancreatic cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



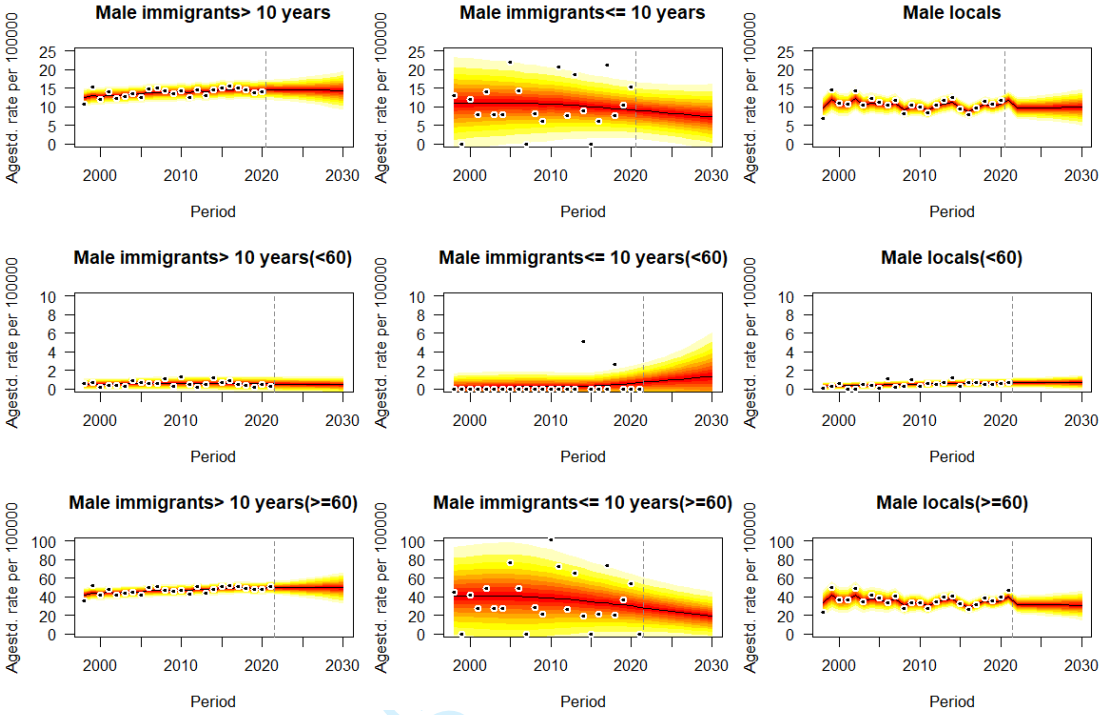
eFigure 5(a). Projections of stomach cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 5(b). Projections of stomach cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 5(c). Projections of stomach cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 6. Projections of prostate cancer mortality rates for males by immigrant status and age groups (less than, greater than or equal to 60 years old) from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Predictive mean of age-standardized mortality rates of lung cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	41.80 (1.27)	41.34 (1.86)	40.58 (2.27)	39.87 (2.75)	39.19 (3.28)	38.53 (3.86)	37.89 (4.46)	37.26 (5.09)	36.65 (5.74)	36.04 (6.4)
Female immigrants ≤ 10	23.92 (4.00)	22.22 (4.67)	20.56 (5.38)	19.01 (6.10)	17.57 (6.80)	16.24 (7.45)	15.00 (8.04)	13.85 (8.56)	12.79 (9.01)	11.81 (9.39)
Female locals	34.67 (1.76)	30.22 (3.54)	30.63 (4.77)	31.05 (6.38)	31.48 (8.29)	31.9 (10.47)	32.32 (12.87)	32.73 (15.48)	33.15 (18.31)	33.55 (21.33)
Male immigrants >10	102.90 (2.43)	100.18 (4.18)	97.18 (5.33)	94.34 (6.72)	91.71 (8.24)	89.15 (9.84)	86.66 (11.47)	84.19 (13.11)	81.81 (14.74)	79.55 (16.37)
Male immigrants ≤10	81.26 (9.21)	79.90 (10.41)	79.81 (11.82)	79.72 (13.42)	79.62 (15.19)	79.50 (17.09)	79.32 (19.09)	79.08 (21.18)	78.78 (23.32)	78.41 (25.53)
Male locals	60.96 (2.82)	52.27 (4.86)	50.83 (5.39)	49.56 (6.13)	48.18 (6.97)	46.64 (7.84)	45.13 (8.76)	43.83 (9.76)	42.67 (10.8)	41.43 (11.8)
Female immigrants>10(<60y)	15.51 (1.12)	14.51 (1.50)	13.90 (1.76)	13.29 (2.04)	12.71 (2.33)	12.13 (2.62)	11.57 (2.91)	11.02 (3.18)	10.49 (3.43)	9.98 (3.68)
Female immigrants ≤ 10(<60y)	8.14 (1.91)	7.79 (1.95)	7.18(2.23)	6.62(2.53)	6.10(2.81)	5.63(3.08)	5.19(3.32)	4.79 (3.53)	4.42 (3.72)	4.09 (3.88)
Female locals(<60y)	10.25 (0.77)	9.48 (0.89)	9.17(1.02)	8.87(1.16)	8.57(1.32)	8.27(1.49)	7.97(1.65)	7.68 (1.82)	7.38 (1.98)	7.09 (2.13)
Male immigrants>10(<60y)	27.81 (2.10)	26.36 (3.58)	24.96 (3.94)	23.64 (4.35)	22.38 (4.79)	21.17 (5.23)	20.03 (5.67)	18.96 (6.10)	17.96 (6.51)	17.03 (6.90)
Male immigrants ≤ 10(<60y)	15.01 (2.98)	13.38 (3.71)	12.02 (4.17)	10.79 (4.59)	9.68 (4.95)	8.69 (5.24)	7.79 (5.46)	6.98 (5.61)	6.25 (5.69)	5.59 (5.72)
Male locals(<60y)	15.19 (0.78)	14.45 (1.15)	14.03 (1.29)	13.61 (1.46)	13.14 (1.64)	12.65 (1.82)	12.13 (2.01)	11.55 (2.17)	10.93 (2.31)	10.26 (2.43)
Female immigrants >10(≥ 60y)	108.85 (4.80)	107.21 (5.17)	106.26 (6.24)	105.52 (7.54)	104.94 (9.04)	104.51 (10.72)	104.21 (12.57)	104.07 (14.61)	104.06 (16.78)	104.16 (19.14)
Female immigrants ≤ 10(≥60y)	66.16 (13.25)	63.84 (15.72)	59.88 (17.50)	56.14 (19.31)	52.60 (21.03)	49.27 (22.66)	46.14 (24.16)	43.20 (25.52)	40.44 (26.74)	37.85 (27.81)
Female locals(≥60y)	77.33 (9.40)	76.53 (10.11)	76.22 (10.85)	75.94 (11.79)	75.69 (12.94)	75.49 (14.28)	75.32 (15.80)	75.19 (17.48)	75.10 (19.33)	75.03 (21.32)
Male immigrants>10(≥60y)	293.56 (9.13)	289.8 (11.7)	286.6 (15.19)	284.28 (19.51)	282.78 (24.49)	281.99 (30.07)	281.88 (36.31)	282.31 (43.15)	283.37 (50.66)	285.03 (58.86)
Male immigrants ≤ 10(≥60y)	244.88 (30.29)	247.01 (36.85)	251.24 (42.94)	255.62 (50.06)	260.14 (58.14)	264.82 (67.14)	269.61 (77.01)	274.52 (87.75)	279.55 (99.34)	284.69 (111.81)
Male locals(≥60y)	150.75 (16.22)	146.29 (18.46)	143.54 (20.58)	141.84 (23.97)	140.07 (28.24)	138.14 (33.39)	136.65 (39.82)	136.49 (47.87)	137.24 (57.47)	138.26 (68.52)

eTable 1. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of lung cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of colon cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	20.03 (0.95)	18.95 (1.13)	18.77 (1.37)	18.59 (1.66)	18.42 (1.98)	18.27 (2.33)	18.12 (2.71)	17.98 (3.11)	17.85 (3.53)	17.73 (3.96)
Female immigrants ≤ 10	8.11 (2.19)	7.70 (2.51)	7.25 (2.81)	6.82 (3.11)	6.42 (3.37)	6.03 (3.61)	5.67 (3.83)	5.33 (4.01)	5.01 (4.17)	4.71 (4.31)
Female locals	13.77 (1.30)	13.47 (1.61)	13.24 (1.72)	13.01 (1.87)	12.77 (2.04)	12.53 (2.24)	12.29 (2.46)	12.06 (2.68)	11.82 (2.92)	11.59 (3.16)
Male immigrants >10	31.22 (1.28)	29.82 (1.46)	29.66 (1.79)	29.52 (2.19)	29.41 (2.63)	29.30 (3.11)	29.21 (3.64)	29.14 (4.19)	29.06 (4.78)	28.98 (5.39)
Male immigrants ≤10	15.47 (2.14)	16.77 (3.77)	17.02 (4.18)	17.23 (4.64)	17.45 (5.14)	17.67 (5.69)	17.88 (6.27)	18.09 (6.91)	18.31 (7.56)	18.50 (8.26)
Male locals	21.28 (1.38)	19.81 (2.07)	19.39 (2.22)	18.97 (2.42)	18.57 (2.61)	18.18 (2.85)	17.81 (3.12)	17.43 (3.40)	17.06 (3.71)	16.71 (4.03)
Female immigrants >10(<60y)	7.09 (0.99)	7.36 (1.12)	7.46 (1.28)	7.56 (1.46)	7.65 (1.68)	7.74 (1.92)	7.83 (2.19)	7.92 (2.48)	8.01 (2.79)	8.09 (3.13)
Female immigrants ≤ 10(<60y)	3.11 (0.67)	2.82 (0.86)	2.65 (0.91)	2.51 (0.97)	2.36 (1.02)	2.22 (1.07)	2.08 (1.11)	1.95 (1.14)	1.83 (1.18)	1.72 (1.22)
Female locals(<60y)	4.10 (0.41)	3.87 (0.50)	3.73 (0.54)	3.61 (0.59)	3.47 (0.65)	3.34 (0.70)	3.22 (0.76)	3.11 (0.82)	2.99 (0.88)	2.88 (0.94)
Male immigrants >10(<60y)	8.29 (0.91)	7.98 (1.17)	7.85 (1.38)	7.71 (1.60)	7.54 (1.83)	7.36 (2.08)	7.17(2.32)	6.97(2.57)	6.76(2.81)	6.55(3.05)
Male immigrants ≤ 10(<60y)	5.03 (1.44)	5.18 (1.58)	5.22 (1.75)	5.26 (1.93)	5.30 (2.14)	5.34 (2.36)	5.38(2.59)	5.43(2.84)	5.47(3.11)	5.51(3.38)
Male locals(<60y)	5.14 (0.43)	4.88 (0.63)	4.66 (0.79)	4.46 (0.96)	4.26 (1.13)	4.08 (1.31)	3.91(1.48)	3.73(1.65)	3.57(1.82)	3.42(1.97)
Female immigrants >10(≥60y)	52.16 (2.59)	49.21 (2.99)	48.70 (3.56)	48.26 (4.26)	47.87 (5.05)	47.54 (5.94)	47.26 (6.90)	47.05 (7.94)	46.91 (9.06)	46.81 (10.26)
Female immigrants ≤ 10(≥60y)	24.01 (5.83)	22.44 (6.56)	21.69 (6.96)	20.95 (7.38)	20.23 (7.80)	19.52 (8.23)	18.84 (8.66)	18.17 (9.08)	17.51 (9.49)	16.86 (9.90)
Female locals(≥60y)	37.42 (5.31)	36.69 (5.74)	36.29 (6.06)	35.87 (6.46)	35.46 (6.95)	35.04 (7.5)	34.61 (8.12)	34.19 (8.79)	33.77 (9.51)	33.34 (10.27)
Male immigrants >10(≥60y)	84.17 (3.55)	82.72 (4.09)	82.16 (4.95)	81.64 (5.97)	81.19 (7.12)	80.81 (8.39)	80.47 (9.77)	80.15 (11.24)	79.85 (12.81)	79.56 (14.45)
Male immigrants ≤ 10(≥60y)	43.25 (11.07)	44.93 (13.09)	45.62 (14.52)	46.30 (16.09)	46.96 (17.80)	47.61 (19.64)	48.25 (21.62)	48.88 (23.73)	49.51 (25.97)	50.13 (28.34)
Male locals(≥60y)	55.79 (6.86)	54.89 (7.65)	53.75 (8.03)	52.63 (8.52)	51.54 (9.12)	50.47 (9.8)	49.43 (10.55)	48.42 (11.37)	47.42 (12.25)	46.44 (13.16)

eTable 2. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of colon cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of liver cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	11.34 (0.66)	10.68 (0.71)	10.09 (0.85)	9.54 (1.01)	9.01 (1.16)	8.50 (1.31)	8.02(1.45)	7.57(1.59)	7.14(1.72)	6.74(1.83)
Female immigrants ≤10	9.15 (1.55)	8.66 (1.82)	8.38 (1.95)	8.11 (2.08)	7.84 (2.22)	7.58 (2.36)	7.32(2.49)	7.07(2.63)	6.82(2.76)	6.58(2.88)
Female locals	6.72 (0.69)	6.36 (0.88)	6.08 (0.90)	5.81 (0.93)	5.53 (0.97)	5.26 (1.01)	5.01(1.06)	4.77(1.11)	4.53(1.15)	4.3(1.21)
Male immigrants >10	52.17 (1.78)	49.22 (2.36)	47.76 (2.93)	46.35 (3.59)	45.01 (4.31)	43.67 (5.05)	42.37 (5.81)	41.1(6.56)	39.89 (7.33)	38.71 (8.08)
Male immigrants ≤10	42.33 (5.87)	39.03 (6.49)	37.39 (7.47)	35.81 (8.51)	34.26 (9.58)	32.76 (10.63)	31.31 (11.65)	29.91 (12.62)	28.56 (13.54)	27.25 (14.40)
Male locals	24.22 (1.77)	22.16 (2.09)	21.02 (2.22)	19.91 (2.39)	18.85 (2.58)	17.83 (2.79)	16.85 (3.03)	15.92 (3.21)	15.03 (3.40)	14.18 (3.59)
Female immigrants >10(<60y)	3.62 (0.45)	3.39 (0.52)	3.29 (0.57)	3.20 (0.63)	3.12 (0.69)	3.04 (0.75)	2.96(0.82)	2.89(0.89)	2.82(0.96)	2.75(1.03)
Female immigrants ≤ 10(<60y)	4.10 (0.79)	3.81 (0.91)	3.69 (0.96)	3.57 (1.02)	3.46 (1.08)	3.36 (1.15)	3.25(1.22)	3.15(1.29)	3.06(1.36)	2.97(1.43)
Female locals(<60y)	1.50 (0.13)	1.37 (0.2)	1.29 (0.21)	1.22 (0.23)	1.16 (0.24)	1.10 (0.26)	1.04(0.27)	0.99(0.29)	0.94(0.30)	0.89(0.31)
Male immigrants >10(<60y)	26.32 (2.11)	24.04 (2.35)	23.02 (2.63)	22.05 (2.94)	21.13 (3.27)	20.25 (3.61)	19.41 (3.95)	18.62 (4.30)	17.86 (4.64)	17.14 (4.98)
Male immigrants ≤ 10(<60y)	25.52 (2.99)	22.56 (3.96)	21.71 (4.44)	20.87 (4.94)	20.04 (5.45)	19.22 (5.95)	18.42 (6.45)	17.63 (6.91)	16.86 (7.36)	16.11 (7.78)
Male locals(<60y)	8.25 (0.69)	7.47 (0.74)	6.97 (0.79)	6.52 (0.86)	6.11 (0.93)	5.73 (1.01)	5.38(1.08)	5.04(1.15)	4.73(1.21)	4.44(1.27)
Female immigrants >10(≥ 60y)	33.67 (1.88)	29.63 (2.01)	27.99 (2.36)	26.42 (2.75)	24.92 (3.14)	23.49 (3.52)	22.13 (3.88)	20.85 (4.23)	19.64 (4.55)	18.50 (4.85)
Female immigrants ≤10(≥ 60y)	21.72 (5.11)	19.08 (5.81)	18.38 (6.14)	17.71 (6.48)	17.03 (6.83)	16.39 (7.16)	15.76 (7.49)	15.16 (7.80)	14.57 (8.11)	14.01 (8.39)
Female locals(≥60y)	20.63 (3.03)	18.41 (3.23)	17.55 (3.26)	16.72 (3.32)	15.91 (3.40)	15.11 (3.49)	14.34 (3.59)	13.59 (3.69)	12.87 (3.81)	12.17 (3.93)
Male immigrants >10(≥ 60y)	115.39 (4.54)	113.96 (5.95)	113.43 (7.65)	113.17 (9.70)	113.16 (12.04)	113.37 (14.66)	113.79 (17.56)	114.39 (20.73)	115.19 (24.18)	116.17 (27.91)
Male immigrants ≤10(≥ 60y)	88.61 (15.58)	85.14 (18.85)	82.59 (20.6)	80.02 (22.44)	77.42 (24.34)	74.83 (26.24)	72.23 (28.12)	69.64 (29.94)	67.07 (31.70)	64.52 (33.38)
Male locals(≥60y)	62.88 (5.97)	58.95 (7.91)	56.51 (8.20)	54.14 (8.61)	51.84 (9.12)	49.61 (9.70)	47.46 (10.33)	45.38 (11.01)	43.38 (11.68)	41.45 (12.36)

eTable 3. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of liver cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of pancreatic cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	10.89 (0.62)	11.11 (0.75)	11.36 (0.91)	11.61 (1.09)	11.87 (1.31)	12.14 (1.56)	12.42 (1.84)	12.71 (2.15)	13.01 (2.48)	13.3(2.85)
Female immigrants ≤ 10	5.51 (1.44)	5.44 (1.56)	5.44 (1.69)	5.43(1.84)	5.42(1.99)	5.41(2.15)	5.39(2.32)	5.36(2.49)	5.34(2.66)	5.31(2.84)
Female locals	8.79 (1.10)	9.01 (1.22)	9.15 (1.34)	9.29(1.48)	9.43(1.64)	9.57(1.83)	9.71(2.05)	9.85(2.28)	9.99(2.54)	10.14 (2.83)
Male immigrants >10	16.30 (0.98)	17.87 (1.19)	18.48 (1.49)	19.11 (1.87)	19.78 (2.32)	20.47 (2.83)	21.18 (3.42)	21.92 (4.07)	22.69 (4.81)	23.49 (5.61)
Male immigrants ≤10	8.10 (2.02)	7.87 (2.37)	7.76 (2.53)	7.64(2.70)	7.51(2.87)	7.38(3.05)	7.24(3.23)	7.09(3.41)	6.95(3.58)	6.81(3.75)
Male locals	11.97 (1.26)	12.29 (1.49)	12.49 (1.64)	12.69 (1.83)	12.91 (2.06)	13.11 (2.33)	13.33 (2.63)	13.55 (2.97)	13.78 (3.34)	14.02 (3.74)
Female immigrants >10(<60y)	3.47 (0.33)	3.62 (0.57)	3.74 (0.66)	3.87(0.77)	4.01(0.89)	4.14(1.02)	4.28(1.18)	4.42(1.34)	4.57(1.53)	4.72(1.73)
Female immigrants ≤ 10(<60y)	1.12 (0.33)	1.21 (0.48)	1.22 (0.52)	1.23(0.56)	1.24(0.61)	1.25(0.66)	1.26(0.71)	1.26(0.77)	1.27(0.83)	1.28(0.89)
Female locals(<60y)	2.76 (0.27)	2.88 (0.36)	2.91 (0.41)	2.93(0.48)	2.96(0.55)	2.99(0.63)	3.02(0.71)	3.04(0.81)	3.07(0.90)	3.10(1.01)
Male immigrants >10(<60y)	6.88 (0.98)	7.05 (1.11)	7.24 (1.32)	7.43(1.56)	7.62(1.84)	7.82(2.16)	8.01(2.50)	8.21(2.88)	8.40(3.30)	8.61(3.75)
Male immigrants ≤ 10(<60y)	2.20 (0.71)	2.01 (0.85)	1.95 (0.91)	1.9(0.94)	1.84(0.99)	1.79(1.04)	1.74(1.09)	1.69(1.14)	1.64(1.19)	1.60(1.24)
Male locals(<60y)	4.16 (0.35)	4.33 (0.48)	4.41 (0.57)	4.46(0.68)	4.53(0.81)	4.61(0.94)	4.69(1.09)	4.77(1.26)	4.85(1.44)	4.93(1.63)
Female immigrants >10(≥60y)	28.58 (1.83)	29.45 (2.11)	29.91 (2.54)	30.38 (3.06)	30.85 (3.66)	31.33 (4.33)	31.81 (5.08)	32.29 (5.91)	32.78 (6.79)	33.27 (7.74)
Female immigrants ≤ 10(≥60y)	16.79 (5.29)	15.65 (6.08)	15.49 (6.71)	15.33 (7.36)	15.16 (8.03)	14.97 (8.73)	14.79 (9.43)	14.59 (10.14)	14.39 (10.86)	14.19 (11.58)
Female locals(≥60y)	22.80 (4.23)	23.85 (4.46)	24.21 (4.81)	24.56 (5.23)	24.91 (5.73)	25.25 (6.30)	25.58 (6.95)	25.90 (7.67)	26.22 (8.47)	26.54 (9.34)
Male immigrants >10(≥60y)	42.70 (2.55)	44.36 (3.02)	45.85 (3.76)	47.41 (4.69)	49.04 (5.78)	50.73 (7.05)	52.48 (8.50)	54.28 (10.13)	56.16 (11.95)	58.11 (13.98)
Male immigrants ≤ 10(≥60y)	24.68 (8.21)	23.96 (9.01)	23.87 (9.74)	23.75 (10.52)	23.61 (11.33)	23.45 (12.17)	23.28 (13.04)	23.09 (13.93)	22.89 (14.83)	22.68 (15.75)
Male locals(≥60y)	30.10 (4.68)	31.17 (5.22)	31.55 (5.63)	31.93 (6.14)	32.30 (6.75)	32.66 (7.45)	33.01 (8.23)	33.35 (9.11)	33.69 (10.08)	34.03 (11.12)

eTable 4. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of pancreatic cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of stomach cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	8.20 (0.55)	7.95 (0.62)	7.71 (0.74)	7.47 (0.87)	7.25 (1.01)	7.03 (1.15)	6.83 (1.29)	6.62 (1.43)	6.43 (1.57)	6.24 (1.71)
Female immigrants ≤ 10	7.51 (1.44)	7.36 (1.56)	7.33 (1.69)	7.30 (1.85)	7.28 (2.01)	7.27 (2.20)	7.27 (2.40)	7.28 (2.61)	7.31 (2.84)	7.33 (3.09)
Female locals	5.26 (0.40)	4.91 (0.52)	4.75 (0.57)	4.61 (0.63)	4.47 (0.71)	4.34 (0.77)	4.21 (0.84)	4.08 (0.91)	3.95 (0.99)	3.83 (1.06)
Male immigrants >10	15.22 (0.64)	13.89 (0.97)	13.34(1.21)	12.81 (1.46)	12.31 (1.73)	11.83 (1.99)	11.38 (2.26)	10.95 (2.51)	10.54 (2.76)	10.15 (3.01)
Male immigrants ≤10	15.83 (3.04)	15.21 (3.38)	15.07 (3.67)	14.93 (3.98)	14.79 (4.31)	14.64 (4.65)	14.51 (5.02)	14.35 (5.39)	14.19 (5.78)	14.03 (6.17)
Male locals	8.14 (0.89)	8.07 (0.99)	7.73 (1.03)	7.41(1.07)	7.10 (1.13)	6.81 (1.19)	6.51 (1.26)	6.23 (1.33)	5.97 (1.39)	5.71 (1.46)
Female immigrants >10(<60y)	4.81 (0.56)	4.69 (0.79)	4.62 (0.87)	4.55 (0.96)	4.47 (1.07)	4.39 (1.17)	4.31 (1.29)	4.22 (1.41)	4.13 (1.52)	4.03 (1.64)
Female immigrants ≤ 10(<60y)	3.89 (0.80)	4.08 (0.93)	4.10 (1.03)	4.13 (1.14)	4.17 (1.27)	4.21 (1.41)	4.24 (1.55)	4.28 (1.70)	4.32 (1.87)	4.36 (2.05)
Female locals(<60y)	2.28 (0.21)	2.08 (0.27)	1.98 (0.29)	1.88 (0.32)	1.79 (0.35)	1.71 (0.37)	1.61 (0.41)	1.53 (0.43)	1.44 (0.45)	1.37 (0.47)
Male immigrants >10(<60y)	4.94 (0.57)	4.71 (0.79)	4.55 (0.89)	4.41 (0.99)	4.25 (1.10)	4.12 (1.21)	3.98 (1.32)	3.86 (1.43)	3.74 (1.54)	3.63 (1.65)
Male immigrants ≤ 10(<60y)	4.81 (1.31)	4.70 (1.42)	4.66 (1.55)	4.63 (1.69)	4.59 (1.83)	4.55 (1.99)	4.52 (2.15)	4.48 (2.32)	4.44 (2.50)	4.41 (2.68)
Male locals(<60y)	2.48 (0.21)	2.37 (0.29)	2.28 (0.32)	2.21 (0.35)	2.12 (0.38)	2.04 (0.42)	1.97 (0.45)	1.91 (0.49)	1.83 (0.52)	1.77(0.55)
Female immigrants >10(≥60y)	17.80 (1.04)	16.23 (1.26)	15.65 (1.47)	15.08 (1.70)	14.55 (1.94)	14.03 (2.18)	13.54 (2.43)	13.07 (2.68)	12.62 (2.92)	12.19 (3.16)
Female immigrants ≤ 10(≥60y)	14.72 (4.29)	13.01 (4.83)	12.52 (5.11)	12.03 (5.37)	11.55 (5.63)	11.08 (5.88)	10.63 (6.12)	10.19 (6.35)	9.76(6.56)	9.34 (6.75)
Female locals(≥60y)	12.20 (1.66)	11.86 (1.84)	11.67 (1.98)	11.49 (2.15)	11.33 (2.35)	11.18 (2.58)	11.04 (2.84)	10.91 (3.11)	10.79(3.4)	10.68 (3.71)
Male immigrants >10(≥60y)	37.23 (2.29)	36.59 (2.56)	35.17(3.18)	33.82 (3.86)	32.55 (4.57)	31.34 (5.28)	30.19 (6.01)	29.08 (6.70)	28.02 (7.40)	27.01 (8.07)
Male immigrants ≤ 10(≥60y)	42.30 (10.88)	41.43 (11.78)	41.03 (12.71)	40.61 (13.70)	40.17 (14.75)	39.71 (15.85)	39.24 (16.99)	38.75 (18.16)	38.23 (19.35)	37.71 (20.57)
Male locals(≥60y)	23.04 (3.29)	22.69 (3.56)	22.37(4.07)	22.16(4.84)	21.89 (5.86)	21.61 (7.22)	21.52 (9.02)	21.74 (11.29)	22.17 (14.03)	22.73 (17.28)

eTable 5. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of stomach cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of prostate cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Male immigrants >10	14.81 (0.61)	14.59 (0.79)	14.57 (0.96)	14.56 (1.15)	14.54 (1.37)	14.51 (1.61)	14.48 (1.86)	14.45 (2.13)	14.42 (2.42)	14.38 (2.72)
Male immigrants ≤10	9.03 (2.95)	8.78 (3.11)	8.58 (3.29)	8.39 (3.49)	8.19(3.69)	8.10(3.89)	7.82(4.11)	7.63(4.31)	7.45(4.51)	7.27(4.72)
Male locals	9.54 (1.40)	9.66 (1.57)	9.67 (1.66)	9.69 (1.77)	9.72(1.91)	9.75(2.06)	9.78(2.23)	9.82(2.43)	9.86(2.64)	9.9(2.88)
Male immigrants >10(<60y)	0.57 (0.12)	0.52 (0.17)	0.51 (0.19)	0.50 (0.21)	0.49(0.22)	0.48(0.24)	0.47(0.25)	0.46(0.27)	0.45(0.29)	0.44(0.31)
Male immigrants ≤ 10(<60y)	0.65 (0.59)	0.73 (0.77)	0.81 (0.93)	0.87 (1.10)	0.94(1.31)	1.01(1.51)	1.09(1.75)	1.16(2.02)	1.24(2.32)	1.33(2.64)
Male locals(<60y)	0.63 (0.12)	0.66 (0.14)	0.66 (0.16)	0.66 (0.19)	0.67(0.21)	0.67(0.24)	0.67(0.27)	0.68(0.31)	0.68(0.33)	0.69(0.37)
Male immigrants >10(≥ 60y)	49.43 (2.59)	49.61 (2.73)	49.63 (3.29)	49.64 (3.94)	49.64 (4.68)	49.64 (5.51)	49.63 (6.38)	49.62 (7.32)	49.61 (8.32)	49.58(9.37)
Male immigrants ≤ 10(≥60y)	28.29 (9.15)	27.66 (9.78)	26.53 (10.21)	25.4 (10.63)	24.28 (11.03)	23.16 (11.41)	22.07 (11.76)	21.01 (12.09)	19.96 (12.38)	18.95(12.63)
Male locals(≥60y)	31.57 (5.17)	31.48 (5.49)	31.40 (5.76)	31.32 (6.09)	31.24 (6.48)	31.15 (6.94)	31.06 (7.44)	30.96 (8.01)	30.86 (8.61)	30.74(9.26)

eTable 6. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of prostate cancer per 100,000 population for each age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Reporting checklist for cohort study.

Based on the STROBE cohort guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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In your methods section, say that you used the STROBE cohortreporting guidelines, and cite them as:

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		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	5
Setting	#5	Describe the setting, locations, and relevant dates, including periods	5

		of recruitment, exposure, follow-up, and data collection	
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up.	5
Eligibility criteria	#6b	For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5
Bias	#9	Describe any efforts to address potential sources of bias	5
Study size	#10	Explain how the study size was arrived at	5
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	5
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	5
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	5
Statistical methods	#12c	Explain how missing data were addressed	5
Statistical methods	#12d	If applicable, explain how loss to follow-up was addressed	n/a
Statistical methods	#12e	Describe any sensitivity analyses	n/a
Results			
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible,	n/a

		included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	5
Participants	#13c	Consider use of a flow diagram	
n/a			
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	5
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	
n/a			
Descriptive data	#14c	Summarise follow-up time (eg, average and total amount)	
n/a			
Outcome data	#15	Report numbers of outcome events or summary measures over time. Give information separately for exposed and unexposed groups if applicable.	
n/a			
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6
Main results	#16b	Report category boundaries when continuous variables were categorized	n/a
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
n/a			
Other analyses	#17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	7

Discussion

Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	10
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

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An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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Abstract

Objectives: To explore the relationship between immigration groups and cancer mortality, this study aimed to explore age, period, birth cohort effects and effects across genders and immigration groups on mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers and their projections.

Design, Setting, and Participants: Death registry data in Hong Kong between 1998 and 2021, which were stratified by age, sex and immigration status. Immigration status was classified into three groups: locals born in Hong Kong, long-stay immigrants and short-stay immigrants.

Methods: Age-period-cohort analysis was used to examine age, period, and birth cohort effects for genders and immigration groups from 1998 to 2021. Bayesian age-period-cohort models were applied to predict the mortality rates from 2022 to 2030.

Results: Short-stay immigrants revealed pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Immigrants for each type of cancer and gender will be at a higher mortality risk than locals, as men will be at a higher risk of mortality from cancers than women in the future (excluding prostate cancer). After 2021, decreasing trends ($p<0.05$) or plateau ($p>0.05$) of forecasting mortality rates of cancers occur for all immigration groups, except for increasing trends for short-stay male immigrants with colon cancer ($p<0.05$, Avg +0.30 deaths/100,000 per annum from 15.47 to 18.50 deaths/100,000) and long-stay male immigrants with pancreatic cancer ($p<0.05$, Avg +0.72 deaths/100,000 per annum from 16.30 to 23.49 deaths/100,000).,

Conclusions: Findings underscore the effect of gender and immigration status in Hong Kong on mortality risks of cancers that immigrants for each type of cancer and gender will be at a higher mortality risk than locals.

Keywords: Age-period-cohort analysis, immigration, mortality, lung cancer, pancreatic cancer, colon cancer, liver cancer, prostate cancer, stomach cancer

Strengths and limitations of this study

- This study provides new evidence regarding the relationship between immigration status and cancer mortality, given the effects of age, period, birth cohort and their predictions.
- The non-identifiability problem has not been interpreted in APC models
- The future perspective of cancer therapies and techniques have not been considered.

Introduction

Several migration waves from mainland China to Hong Kong have occurred over the past century. These migration waves included a large-scale migration inflow from 1945 to 1950 (the Chinese Civil War) and a few small-scale inflows in the 1950s, 1970s, and 1990s [1-3]. In 2016, immigrants from mainland China formed approximately 38% of the population of Hong Kong. These inflows have led to a growing interest in research on the disparity of health conditions between the locals and immigrants.

Cancer has been one of the most common causes of death, as an estimated 19.3 million new cancer cases and 9.9 million new cancer-associated deaths occurred worldwide in 2020 [4]. In Hong Kong, lung cancer is one of the most common causes of cancer deaths [5, 6]. Previous studies suggested that the primary cause of lung cancer is cigarette smoking [7-11]. Genetic factors, asbestos, radon gas, second-hand smoke, and other forms of air pollution have been proven to influence the risk of lung cancer [12-18]. The overall daily smoking rate in mainland China was approximately 23.2% in 2018 [19], whereas the daily smoking rate in Hong Kong was only 10.2% in 2019 [20]. The leading causes of liver cancer include viral infection, drinking of alcohol and polluted water and food supplies which are also culprits for colon, stomach and pancreatic cancer [21]. Alcohol consumption per capita in Hong Kong has reached 2.37 liters in 2021 [22], compared to 7.0 liters of per capita consumption of alcohol in mainland China in 2018 [23]. As approximately 99% of prostate cancer cases occur after age 50, factors of prostate cancer have been regarded as old age, race, family history and the diet of red meat consumption [24]. In addition to these risk factors, studies have suggested that cancer mortality rates vary depending on migrant status [25-28]. According to data from the Census and Statistics Department of Hong Kong, approximately 81% of immigrants in Hong Kong immigrated from mainland China, Macau, and Taiwan. Immigrants from mainland China account for the bulk of this population. Previous studies have shown that child immigrants in Hong Kong tend to suffer from a higher risk of wheezing disorders and cardiovascular diseases, and immigrant women have higher age-specific mortality rates of breast cancer than locally-born women in Hong Kong [29, 30]. However, to date, few studies have investigated the effect of length of stay in Hong Kong and birthplace on the risk of other types of cancer.

In this study, we compared the mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers between locally born residents in Hong Kong and immigrants from mainland China. Both populations are widely considered as ethnically homogeneous with similar cultures. Nevertheless, due to different early life experiences, immigrants are exposed to more various social economy and lifestyles than locals. Therefore, it's constructive to ascertain whether immigrants from mainland China have a different mortality pattern of cancers from locals to

verify the significance of migration status for this health outcome. As Age-period-cohort (APC) analysis plays a vital role in studying time-specific phenomena in epidemiology, in this study, to evaluate the effect of immigration on cancer mortality in the past and future, we developed APC models specified by sex and migrant status to assess the effects of age, period, birth cohort, and of the length of stay in Hong Kong on the mortality risks of cancers. Additionally, we explore the projection of mortality rates for the locally born population and immigrants in Hong Kong who were younger or older than 60 using a predictive model, taking into account age, period, and birth cohort effects as well.

Methods

Data

We obtained the death registry data in Hong Kong between 1998 and 2021 from the Census and Statistics Department of Hong Kong, as the data in 2022 has not been available up to now. The data was extracted from a routine census held by the Hong Kong government as subjective errors caused by resampling can be neglected. The population data were stratified by age, sex, immigration status, and length of stay in Hong Kong. We retrieved six types of cancer cases from the death registry data using ICD codes, such as ICD-9 code 162 and ICD-10 codes C34.0–C34.3, C348, and C349 for lung cancer. To assure comparability among registries, deaths from the age group of 35–85 years were selected, since cases younger than 35 and older than 85 were relatively trivial for lack of statistical interpretability [31]. Immigration status was classified into three groups: locals born in Hong Kong, immigrants who have lived in Hong Kong for >10 years before death defined as long-stay immigrants, and immigrants who have lived in Hong Kong for ≤10 years before death defined as short-stay immigrants. Notably, much focus was placed on immigrants from mainland China, because approximately 81% of immigrants in Hong Kong came from mainland China, Macau, and Taiwan based on the data from the Census and Statistics Department of Hong Kong. Moreover, few cases recorded from Macau and Taiwan are statistically insignificant in the analysis. Demographics and population projections from 2022 to 2030 were retrieved from the Census and Statistics Department of Hong Kong and estimated with cubic smoothing spline as the prerequisite of the predictive model. Codes for APC and BAPC analysis are available in the GitHub repository (https://github.com/kshz2164313/APC-population-projections-for-immigration-HK).

Statistical analysis

We modeled cancer mortality rates in Hong Kong using APC analysis based on log-linear Poisson regression models. The model aimed to disentangle age, period, and cohort effects of time-varying phenomena simultaneously [32, 33], given that

$$\log(E_{ij}) = \alpha_i + \beta_j + \gamma_k + \mu + \log(\theta_{ij}) \quad (1)$$

where E_{ij} denotes expected mortality; α_i, β_j, and γ_k denote age, period, and cohort effect, respectively, for $i = 1,...,I$, $j = 1,...,J$, $k = 1,...,K$ with $k = I - i + j$. $\log(\theta_{ij})$ is the offset. We mainly focused on the contributions of sex and immigration status due to the non-identifiability problem that the effects of these three components are collinear with each other (denoted as period – age = cohort) [34]. Birth cohort effect and period effect were assessed with relative risks to evaluate the effect of three components. The median year of birth among cases was regarded as the reference cohort [35,36]. Since death cases aged at 35–85 years between 1998 and 2021 were selected, the range of birth cohort from 1913 to 1986 covered observations and further projections until 2030. The second and penultimate period effects were constrained to the reference for period. For sex and immigration status, maximum likelihood framework was applied to estimate the relative risks and 95% confidence intervals (CIs) by age groups, calendar period, and birth cohort.

Several projection approaches for future cancer mortality have been developed, but a Bayesian age-period-cohort (BAPC) model built upon integrated nested Laplace approximations (INLA) [37] yields relatively higher coverage and better performance for all evaluated parameter combinations [38]. To prevent some sampling problems caused by Markov chain Monte Carlo (MCMC), this MCMC-free BAPC approach was applied to predict future cancer mortality within a fully Bayesian inference setting and provide outputs of interest simply, such as projected age-standardized and age-specific rates. Convergence checks are not necessary for this technique [37]. The projections of age-standardized cancer mortality rates for each sex, age group (younger or older than 60 years) and migrant status, taking into account age, period, and birth cohort effects, were performed based on the weights of population age groups from the WHO World Standard population [39], with 95% prediction intervals. Mann-Kendall trend test was applied to verify the projection trend. Friedman's Two-Way Analysis of Variance was applied to test interactions between gender and immigration groups for each year.

All analyses were performed via R version 4.2.1 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria, 2013, http://www.R-project.org/). The APC models were established using the Epi package, and the projections based on Bayesian APC models were performed with the BAPC package.

Patient and Public Involvement

None.

Results

Figure 1 & 2 and eFigure 1(a-e) in **Supplementary Material** illustrate the estimates of age

(assessed by cancer mortality), cohort and period effects (assessed by relative risk) based on APC models among three migrant groups for men and women with six types of cancers, respectively. All the mortality rates for each gender and immigration status exhibit notable increasing trends with age. Age, cohort and period effects of six types of cancer for immigrants who stayed in Hong Kong for ≤10 years revealed relatively more pronounced fluctuations and deviations from those effects in the other two immigration groups. Significant increasing trends of age effect occurred in all types of cancer, regardless of gender and immigration status. For example, while relatively insignificant differences in lung cancer mortality rates by immigration status among females have performed, male immigrants who remained in Hong Kong for >10 years had higher lung cancer mortality rates at ages above 50 years and those who arrived ≤10 years had lower lung cancer mortality at ages below 62 years compared to local men Figure 1. In addition to compatible dynamics of period effect for locals and long-stay immigrants, similar changes of relative risks by birth cohort for locals and long-stay immigrants in lung, colon, liver and stomach cancers occurred before 1945, whereas significant differences of relative risks by birth cohort between these two immigration groups occurred after 1960 (Figure 1 & eFigure 1(a,b,d)). Locals and long-stay immigrants in pancreatic and prostate cancer perform almost similar changes of relative risks by birth cohort effects all the time (eFigure 1(c,e)). Short-stay immigrants who have stayed in Hong Kong for ≤10 years had more fluctuating relative risks affected by period effects before 2020 than those for locals and long-stay immigrants. Lack of young cases, especially young short-stay immigrants, of prostate cancer leads to significant deviations and variances in age and cohort effects.

Figure 3-5, eFigure 2-6 in **Supplementary Material** illustrate the age-standardized mortality rates of six types of cancer from 1998 to 2021 and their projections by sex, immigrant status and age groups from 2022 to 2030, taking into account age, period, and birth cohort effects. Means and standard deviations of predictive mortality rates are shown in eTable 1-6 in **Supplementary Material**. For all ages projection (Figure 2 & eFigure 2-6), as men will be at higher risk of mortality rates of cancers (excluding prostate cancer) than women in the future for all three age groups (all ages, young and older than 60 years) and approximately significant interactions between gender and immigration groups emerge for each type of cancer in each year ($p<0.05$), given the projected trends, immigrants for each gender, especially who have stayed in Hong Kong for > 10 years will suffer from higher mortality rates of cancer in each year than locals. Monotone decreasing trends or plateau of forecasting occur for both genders and all immigration groups in cancers, except for increasing trends for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer ($p < 0.05$, Avg +0.30 deaths/100,000 per annum) from 15.47 deaths/100,000 (95% CI: 11.28, 19.66) in 2021 to 18.50 deaths/100,000 (95% CI: 2.31, 34.69) in 2030, and male immigrants who have stayed in Hong Kong for > 10 years with pancreatic cancer ($p < 0.05$, Avg +0.72 deaths/100,000 per annum) from 16.30

deaths/100,000 (95% CI: 14.38,17.26) in 2021 to 23.49 deaths/100,000 (95% CI: 12.49, 34.49) in 2030. Most of predictive trends for younger cases (<60 years) and older cases (≥60 years) reach a consensus with those for all ages population, except for two phenomena: 1.) mortality rates of lung cancer for men immigrants ≤10 that insignificant trend for all ages ($p > 0.05$) vs. decline for younger cases ($p < 0.05$) vs. increase for older cases ($p < 0.05$); 2.) mortality rates of liver cancer for men immigrants >10 that decline for all ages ($p < 0.05$) vs. decline for younger cases ($p < 0.05$) vs. insignificant trend for older cases ($p > 0.05$). Some particular cases occur in the projection of prostate cancer that young long-stay male immigrants (0.44 deaths/100,000, 95% CI: 0, 1.05) aged less than 60 will be at lower mortality rate than locals (0.69 deaths/100,000, 95% CI: 0, 1.42) in 2030 (eTable 6). Compared with other cancers and immigration groups, male immigrants who have stayed in Hong Kong for >10 years with lung cancer would perform the most significant decline in predictive mean from 102.90 (95% CI: 98.14, 107.66) to 79.55 (95% CI: 47.46, 111.64) deaths per 100,000 population (Avg -2.34 deaths/100,000 per annum) (eTable 1), while the same immigration group with pancreatic cancer would indicate the most significant uptrend in each year of 16.30 (95% CI: 14.38,17.26) and 23.49 (95% CI: 12.49, 34.49) deaths per 100,000 population in 2021 and 2030, respectively (Avg +0.72 deaths/100,000 per annum) (eTable 4).

Discussion

Early detection of cancer is positive and instructive for increasing chances of cure. Nevertheless, the high mortality rate of cancer results from late diagnosis among most patients after progression to more advanced or severe stages. Individuals at high risk of cancer, such as smokers, alcoholics or those who are frequently exposed to susceptible circumstances, should be screened for early detections to increase opportunities for cure [40]. Therefore, the differences in mortality rates among immigration groups are synonymous with detection means, therapies, and social history in disparate periods and areas.

While the changes in mortality rates by age for long-stay immigrants reached approximate harmony with those for locals, the changes in mortality rates by age for short-stay immigrants revealed clear differences with those for the other two populations. The group of long-stay immigrants had a higher risk of death from lung, colon and liver cancers than the other two immigration groups after the age of 60 years. Short-stay male immigrants were less likely to die from lung cancer before the age of 65 years. The contrast in age effects among the immigration groups was partially consistent with studies [25, 41] that highlighted the age effects for locals and immigrants on breast cancer mortality in Hong Kong and lung cancer

incidence in Sweden, as they both showed similar trends and magnitudes between locals and immigrants before the age of 60 years. They are also compatible with the results in [42] that diagnosis of liver cancer is the most frequent among populations at 55 to 65 years old. According to these trends, young individuals, especially new young immigrant men, who have benefited from all-rounded development in mainland China and Hong Kong, are more likely to seek early detection and be treated for cancers using more advanced treatments [43]. Differences in birth cohort effects among immigrant groups partially comply with the interpretation above.

We observed significant trends of cohort effects among locals and immigrants. These findings are partially consistent but subtly different from previous findings, regarding the effect of immigration status on cancers. Zhao et al. [25] described multiple peaks of cohort effects on breast cancer mortality between locals and immigrants in Hong Kong, as well as a significant decline in cohort effects after 1950. In contrast, Sung et al. [44] investigated the difference in breast cancer incidence between Chinese Americans and non-Hispanic whites in the U.S. and emphasized that Chinese Americans were at lower risk of breast cancer than non-Hispanic whites born in the same year. Here, we interpret the cohort-driven trends resulting from the intricacy of social history and lifestyle. Compared to a relatively stable social development in Hong Kong, representing downward trends of relative risks for locals, wars and social instability in mainland China resulted in several immigration waves from mainland China to Hong Kong before 1950. Additionally, remarkable increasing trends were recorded for new immigrants after 1950, which corresponded to the economic downturn after wars and famine between 1959 and 1961 during their youth [45]. The increasing trends for new immigrants and similar trends for locals and long-stay immigrants were consistent with the finding that nutrient deficiency contributes to a higher risk of severe mortality rates of cancers [46]. Furthermore, we speculate that these trends, especially those for locals and long-stay immigrants, are most likely attributed to social development and personal behaviors, such as daily habits, occupational history, different diagnoses and treatments, and domestic environmental exposures. Notably, short-stay immigrants suffered from a lower risk of death from colon cancer for all ages (eFigure 1a in **Supplementary Material**). As locals and immigrants in Hong Kong transitioned to more westernized lifestyles, higher consumption of meat was associated with a higher risk of these types of cancer, whereas consumption of vegetables had a strong protective effect against pancreatic cancer, and moderate consumption of coffee appeared to be beneficial against lung cancer [47,48]. Further studies on potential risk factors are required.

Short-stay immigrants had more fluctuating and non-stationary but inconspicuous relative risks by period effects before 2021 than locals and long-stay immigrants. Cumulatively, an

arch pattern and fluctuating curve depicting period effects externally resulted in an arch pattern of age-standardized mortality rates for short-stay immigrant women and irregular rates for short-stay immigrant men before 2021. The external performance of different period effects on mortality rates could be most likely attributed to the higher effect of different lifestyles and social development on new immigrants than on long-stay immigrants and locals in Hong Kong. For the age-standardized mortality rates and projections, consistent with previous findings [49,50], we predict that the mortality rates of cancer in Hong Kong after 2021 will continue to decline or remain relatively stable, consistent with the trends before 2020, except for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer. Men will be at higher risk of mortality rates of cancer than women, regardless of immigration status. They are also compatible with the results in [4] that men suffer from a higher risk of these types of cancer than women, excluding prostate cancer. Furthermore, new immigrant women will be at lower risk than local women, even though long-stay immigrants will suffer from higher mortality rates than locals in the future. Potential interpretations could be consistent with those for birth cohort effects, as age and period effects are considered as confounders of cohort effect.

In the past few decades, spurred by an increasing burden of high incidence and mortality rates of cancer, several studies focused on the inherent identification dilemma of three effects in the APC model. Further, complicated population distribution and immigration status in Hong Kong, one of the areas with the highest population density and migration frequency in the world, have intricate causes and inherent dynamics of cancer and other diseases. To our knowledge, few studies have assessed the relationship between immigration status and cancer mortality. Therefore, this study is original to examine the effect of the length of stay in Hong Kong and origins of previous residence on cancer deaths, which is instructive for further immigration policy-making and targeted strategies of disease detection and intervention. However, this study had several limitations. Given the non-identifiability problem in age-period-cohort models, we could only depict trends and variations among different immigration and sex groups, as illustrated in figures, and insufficiently perform the estimates of the contributions of three effects or subgroups to mortality rates. Furthermore, we adopted a cubic smoothing spline to estimate populations of immigrants and locals due to the large proportion of unspecified immigration status from official demographic projections. A few acceptable cases resulted in a limited type of cancer so that some common cancers, such as the ovary and cervix, were discarded. Since the issue of quantification, the future perspective of cancer therapies and techniques have not been considered in the model of projection.

Conclusion

We conclude that immigrants, especially short-stay immigrants, had more pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Men will be at a higher risk of mortality rates of six types of cancer than women in the future. Male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer would perform significant uptrend in the future, while other immigration groups for each type of cancer would continue to decline or remain relatively stable. Immigrants for each gender in Hong Kong would suffer from higher mortality risks of cancers than locals in the future.

Declaration

Ethical approval and consent to participate

Ethical approval and consent to participate are not applicable. This study does not involve human participants. Data was obtained from the Census and Statistics Department of Hong Kong.

Consent for publication

Not applicable.

Data Availability Statement

Data are available upon reasonable request.

Author contributions

Yanji Zhao: Methodology, Formal analysis, Data Curation, Writing - Original Draft, Visualization
Zian Zhuang: Methodology, Formal analysis, Data Curation, Writing - Review & Editing
Lin Yang: Validation, Writing - Review & Editing
Daihai He: Conceptualization, Writing - Review & Editing, Supervision

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Conflict of interest

None declared.

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None.

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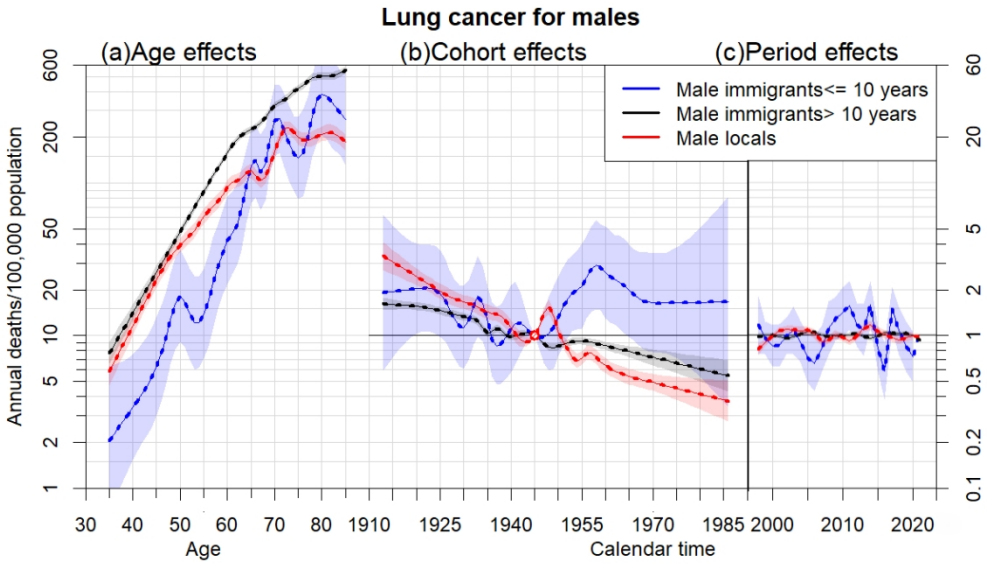
Figure 1. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

Figure 2. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of female lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

Figure 3. Projections of lung cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 4. Projections of lung cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 5. Projections of lung cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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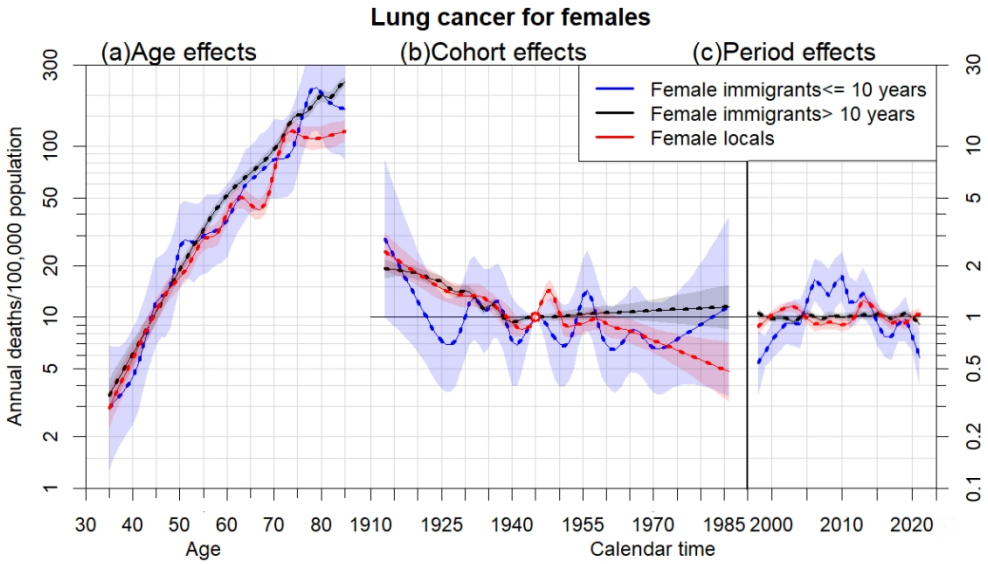

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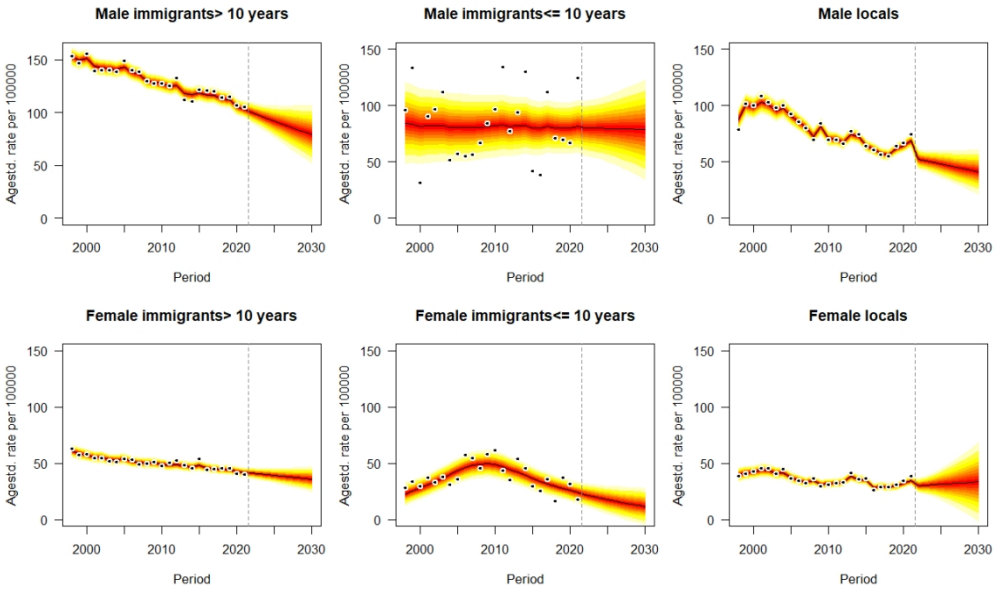

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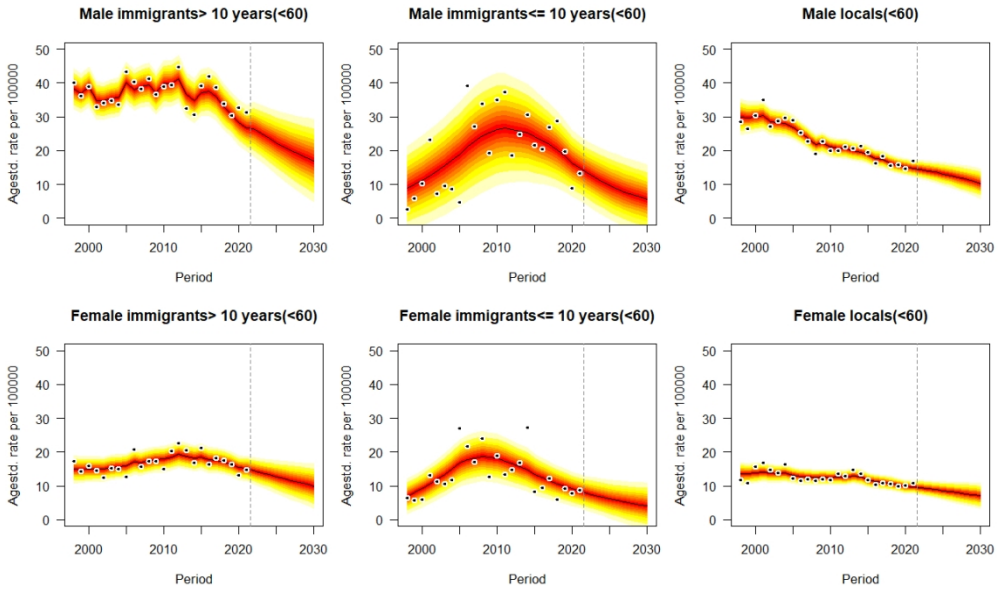

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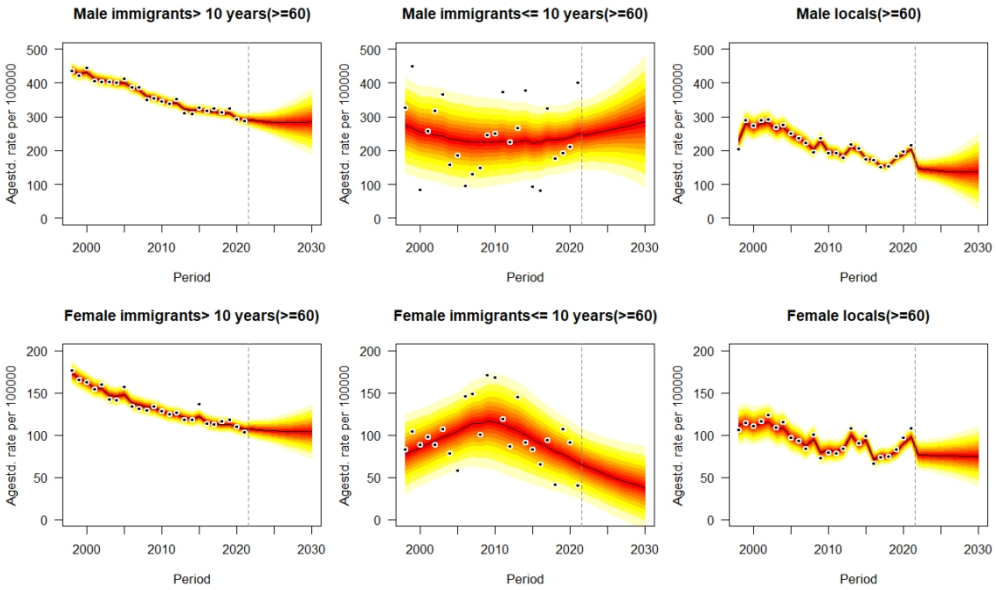

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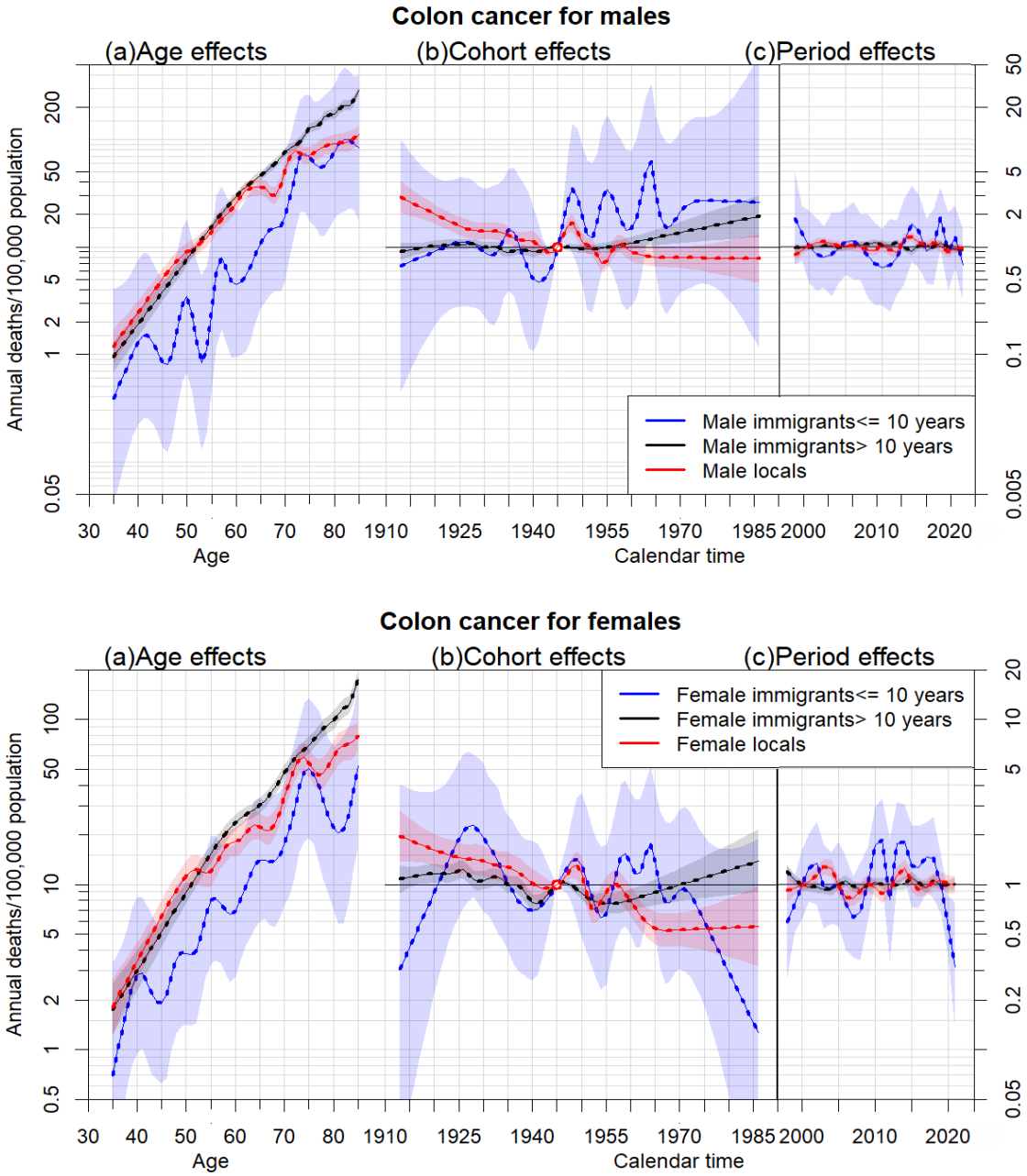
Supplementary Material for

"An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030"

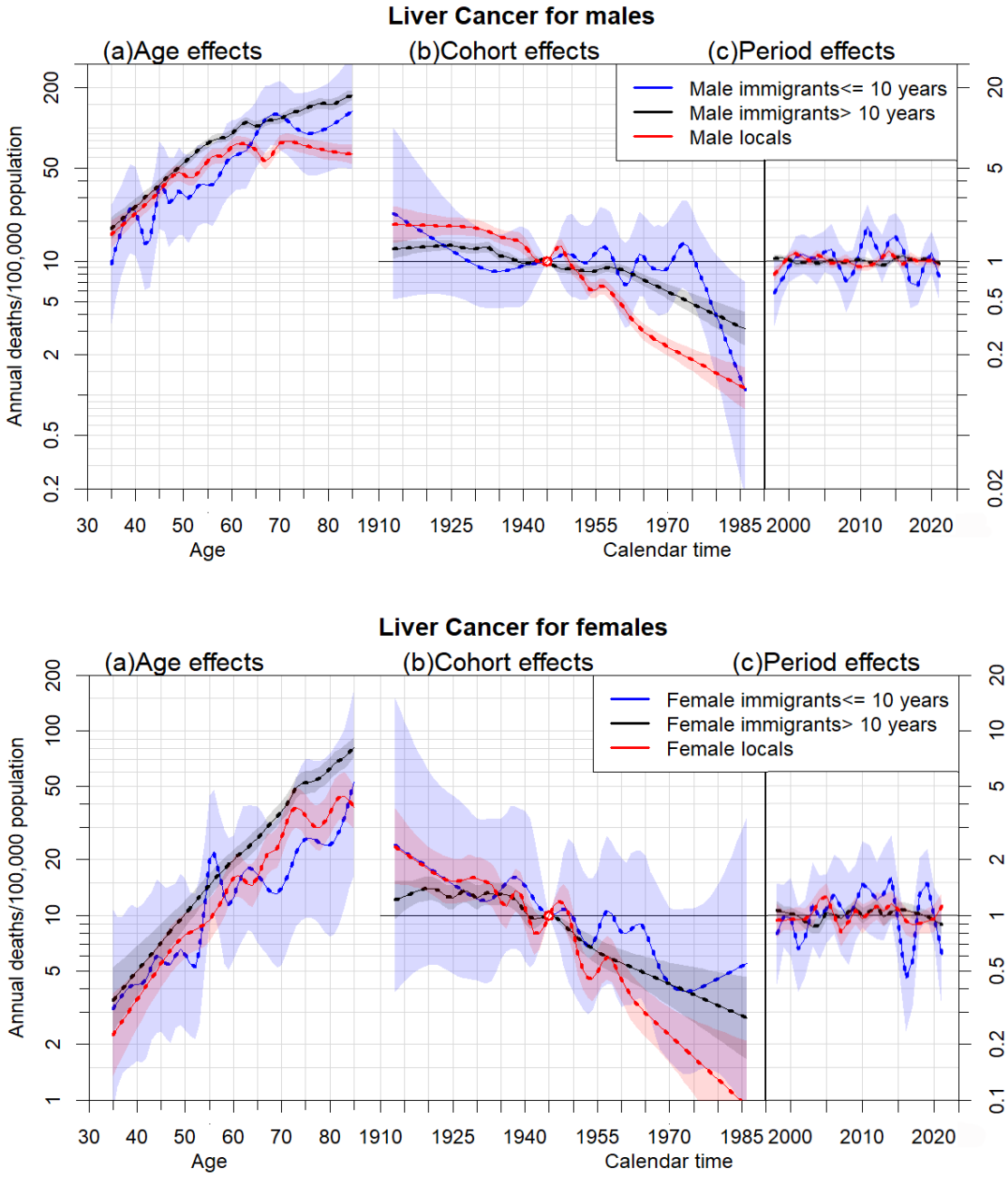
APC Figures

Projection Figures

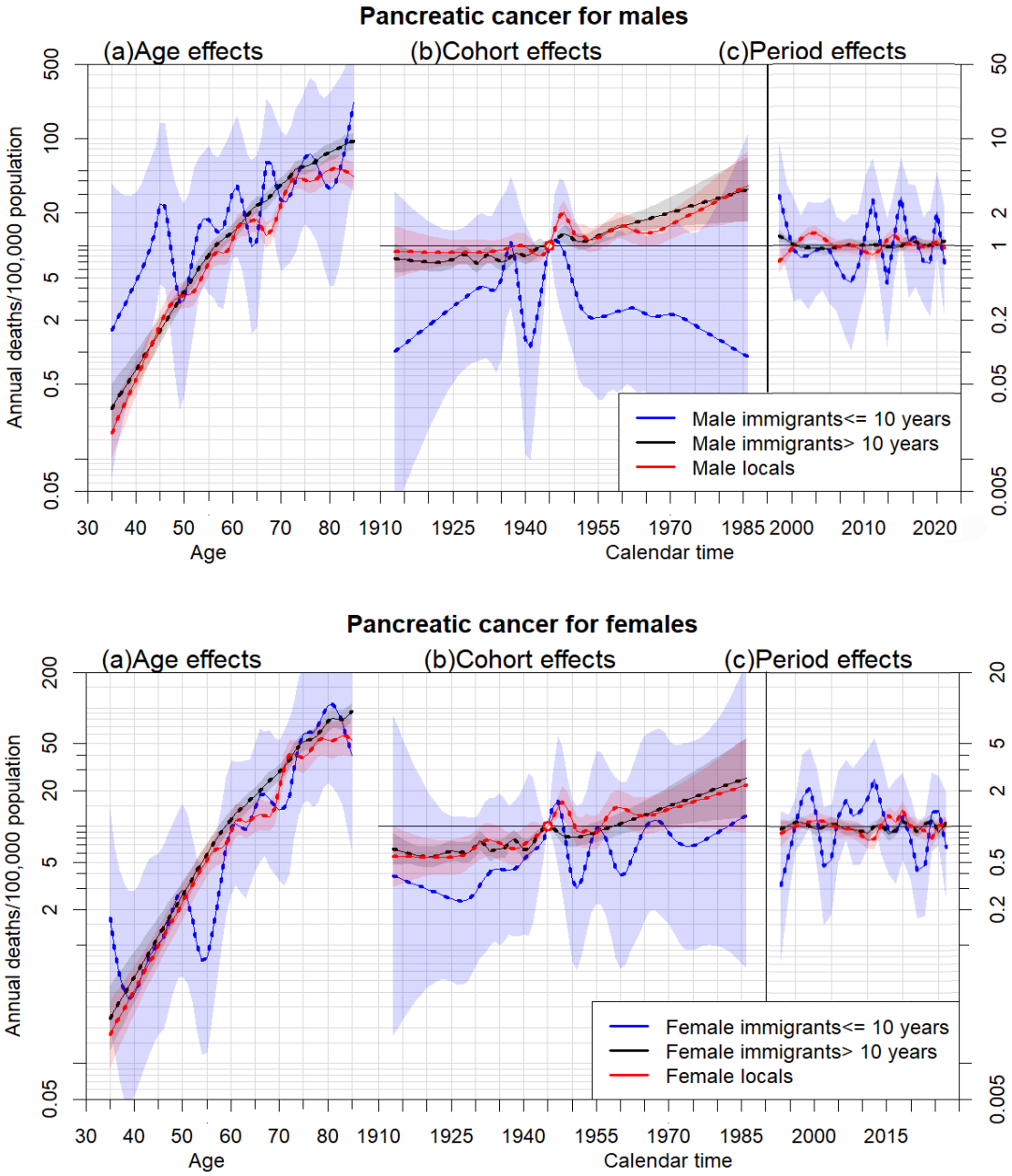
Tables



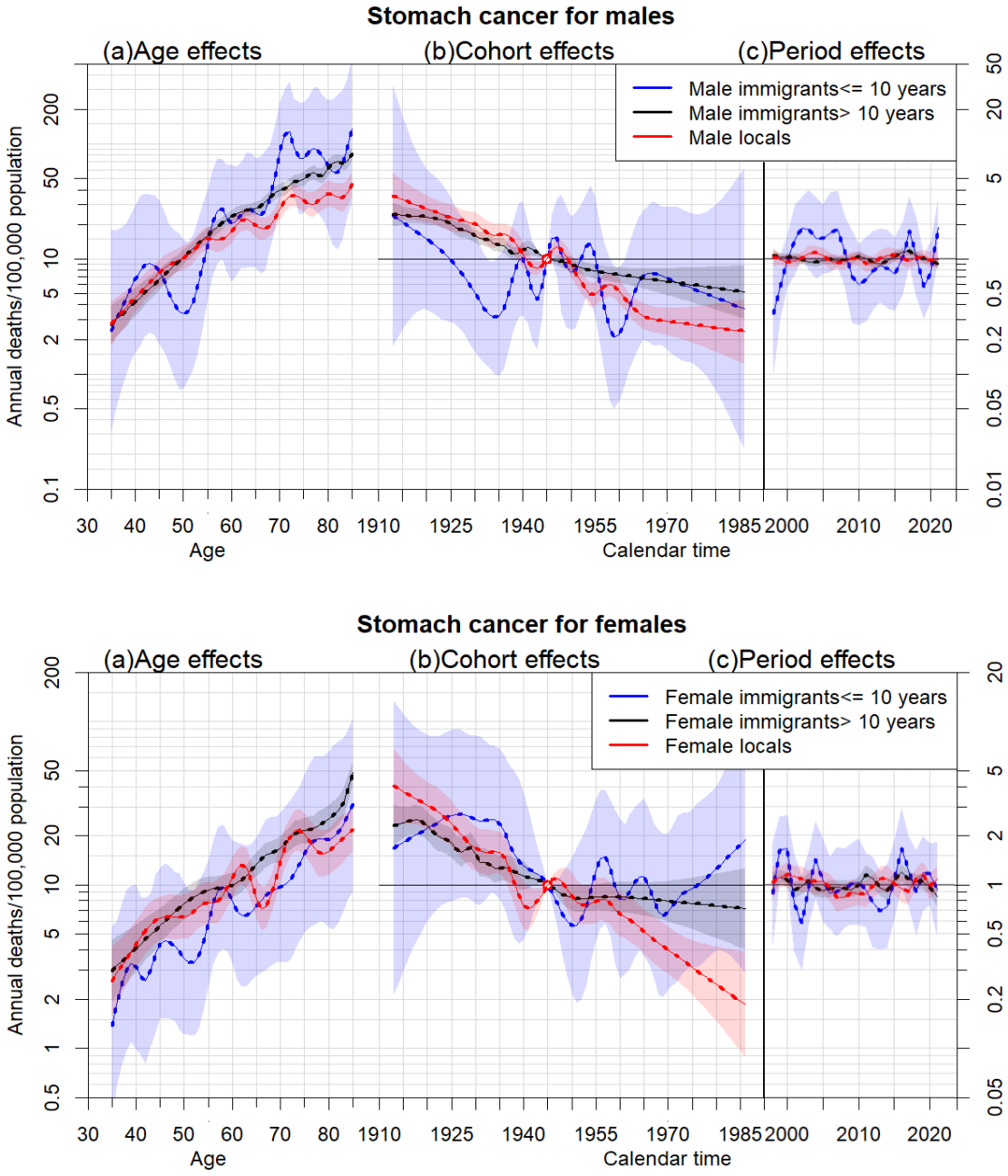
eFigure 1(a). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female colon cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



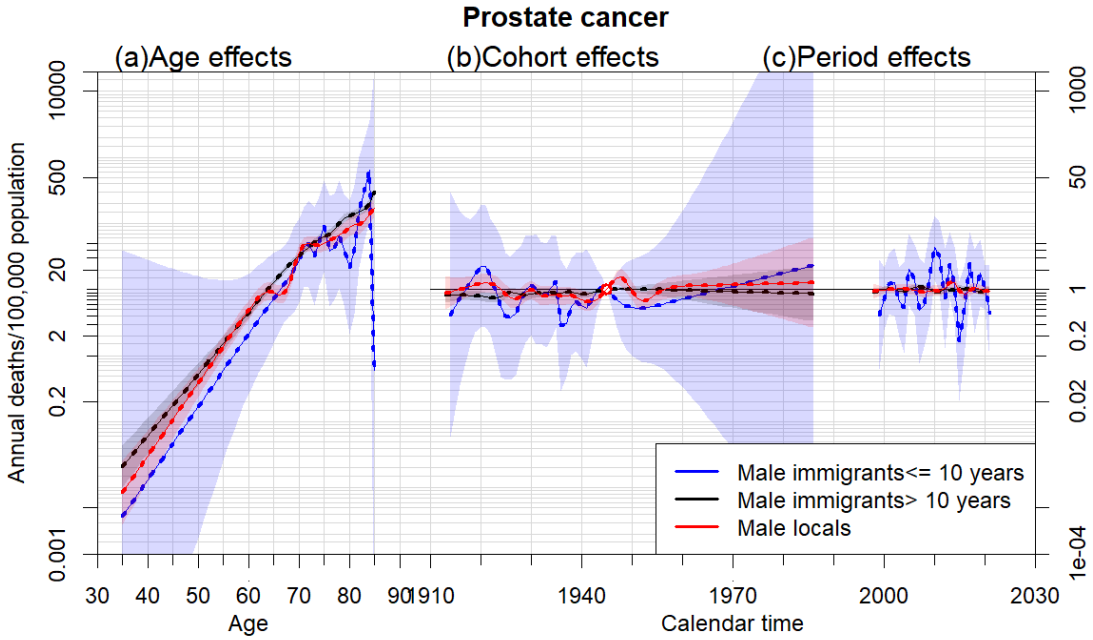
eFigure 1(b). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female liver cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



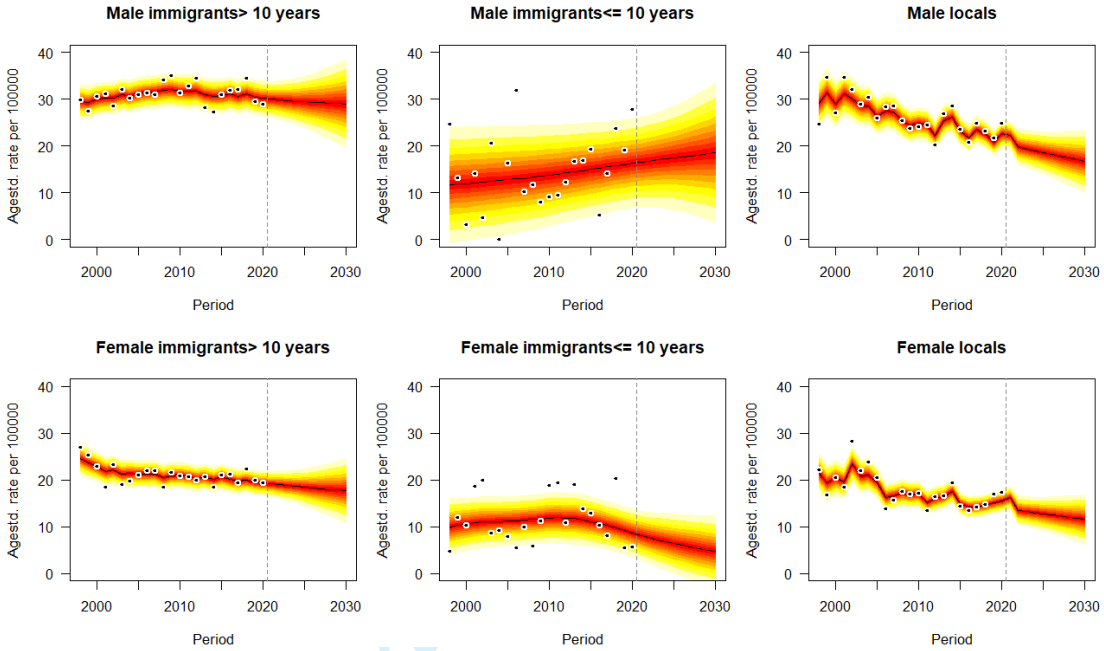
eFigure 1(c). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female pancreatic cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



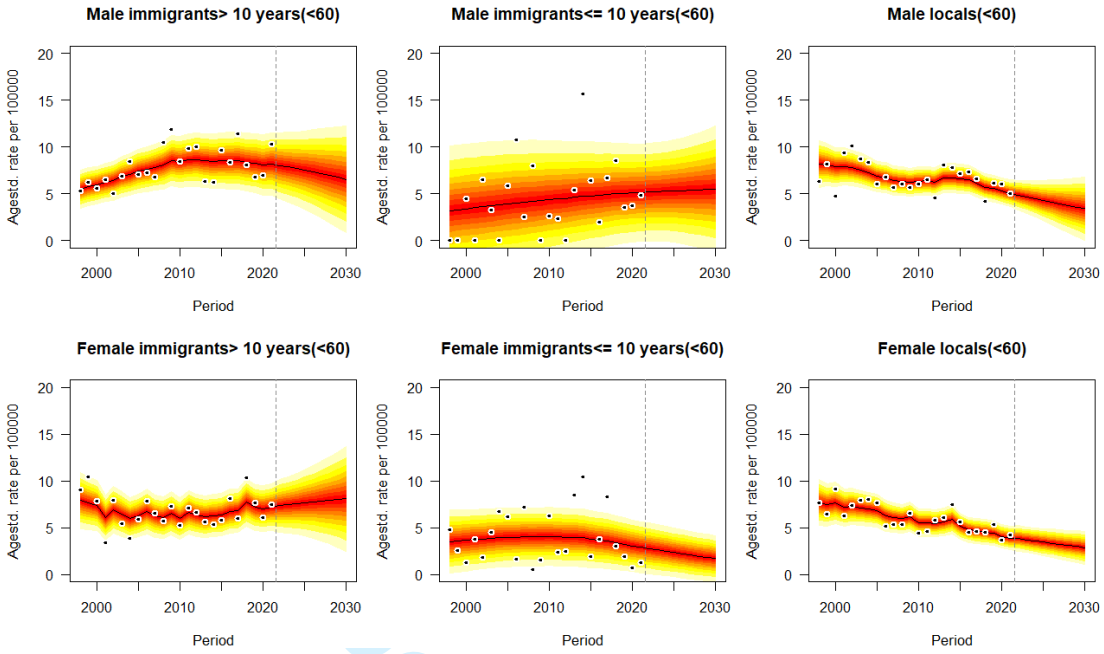
eFigure 1(d). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female stomach cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



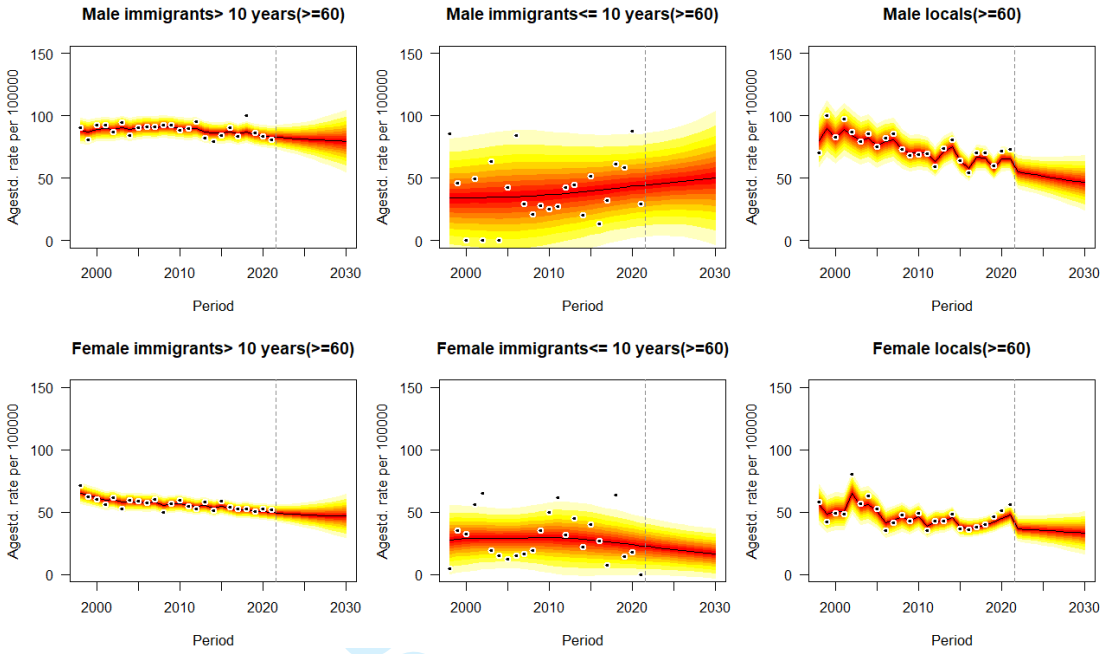
eFigure 1(e). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male prostate cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



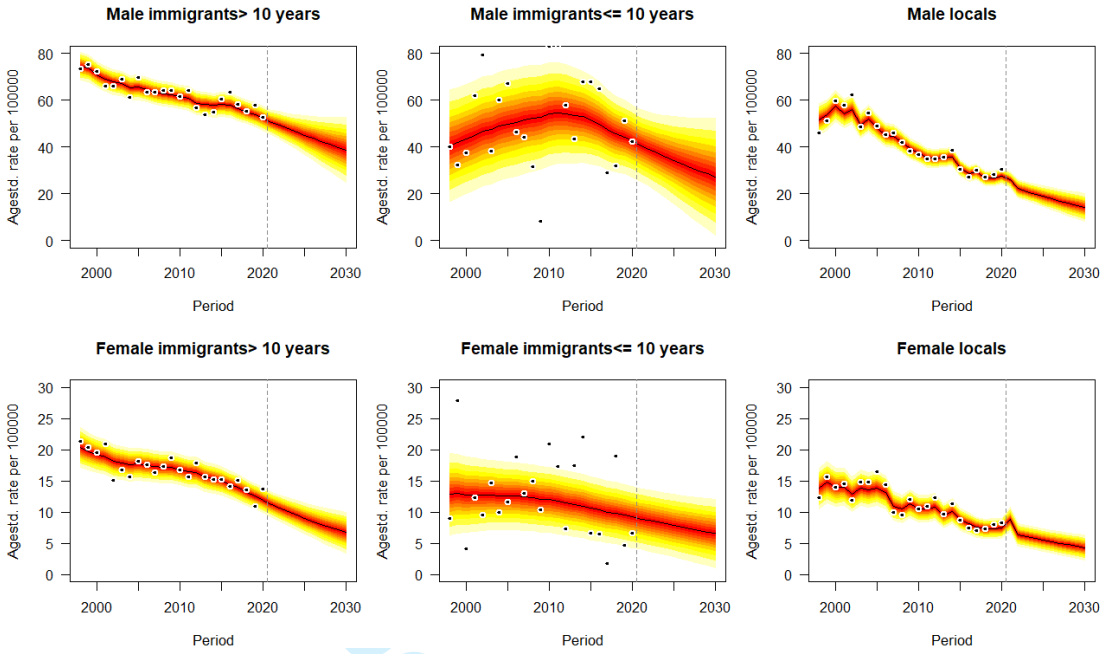
eFigure 2(a). Projections of colon cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



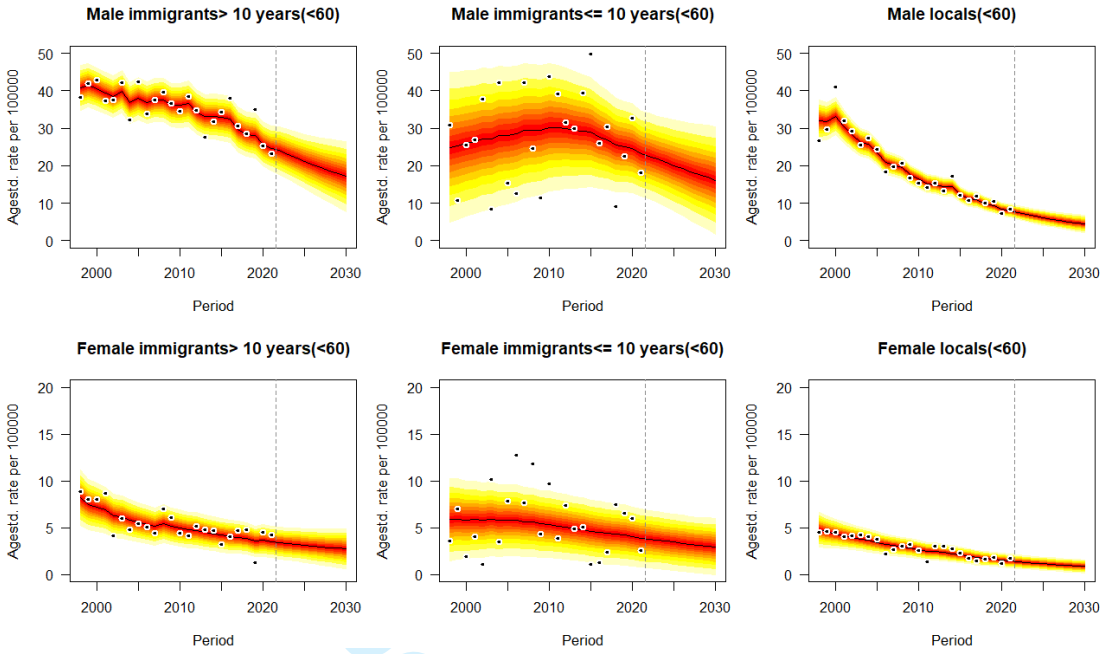
eFigure 2(b). Projections of colon cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



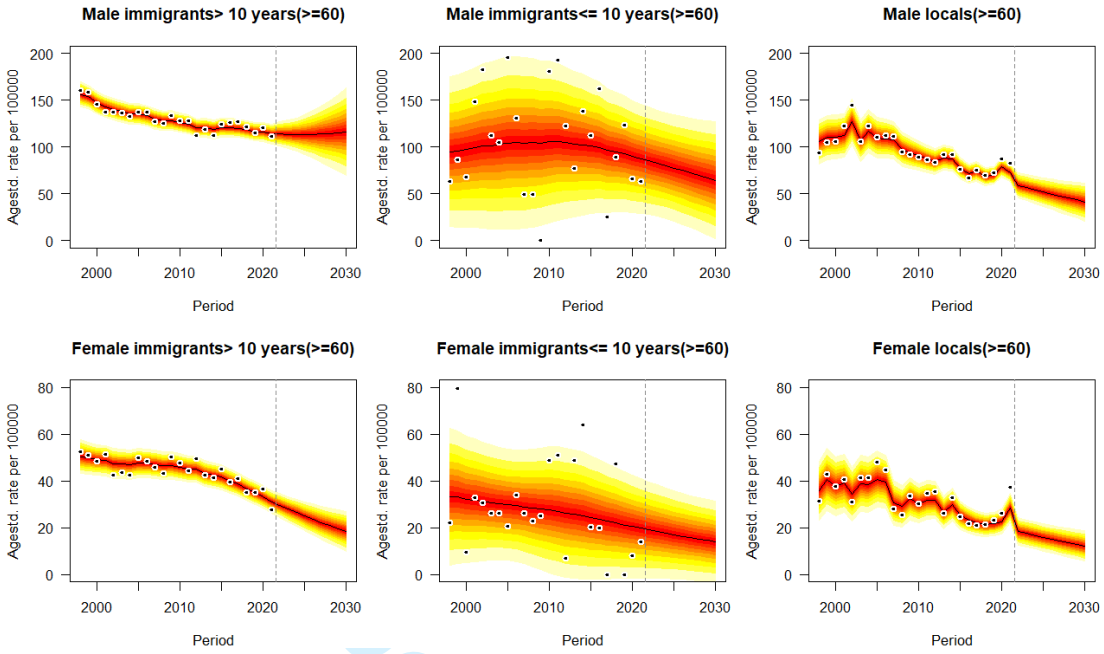
eFigure 2(c). Projections of colon cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



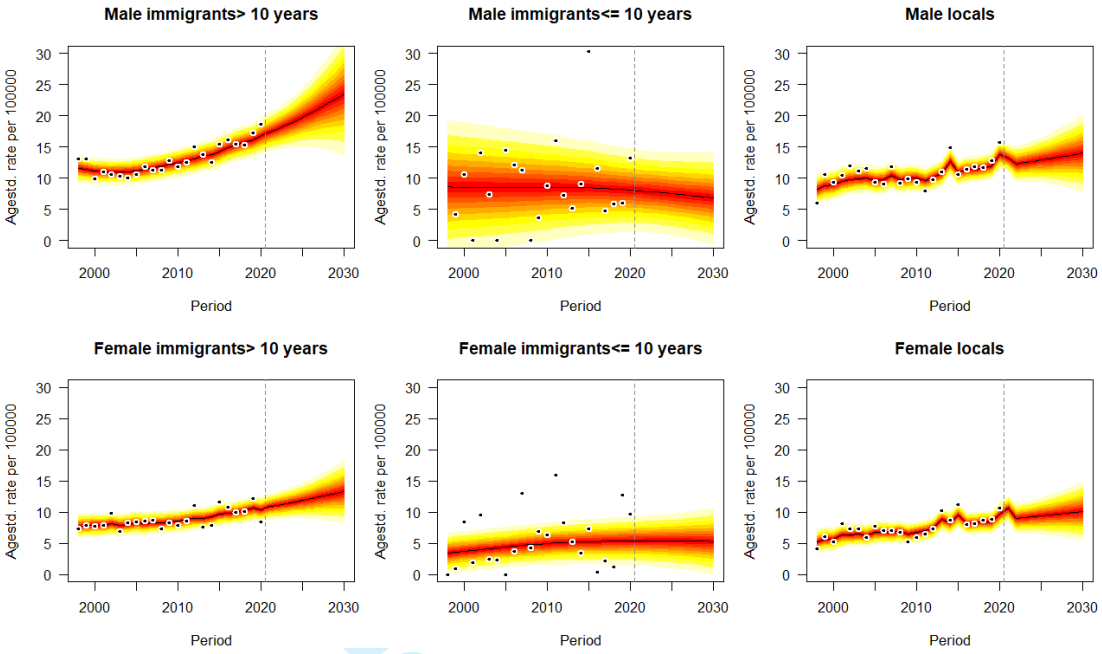
eFigure 3(a). Projections of liver cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



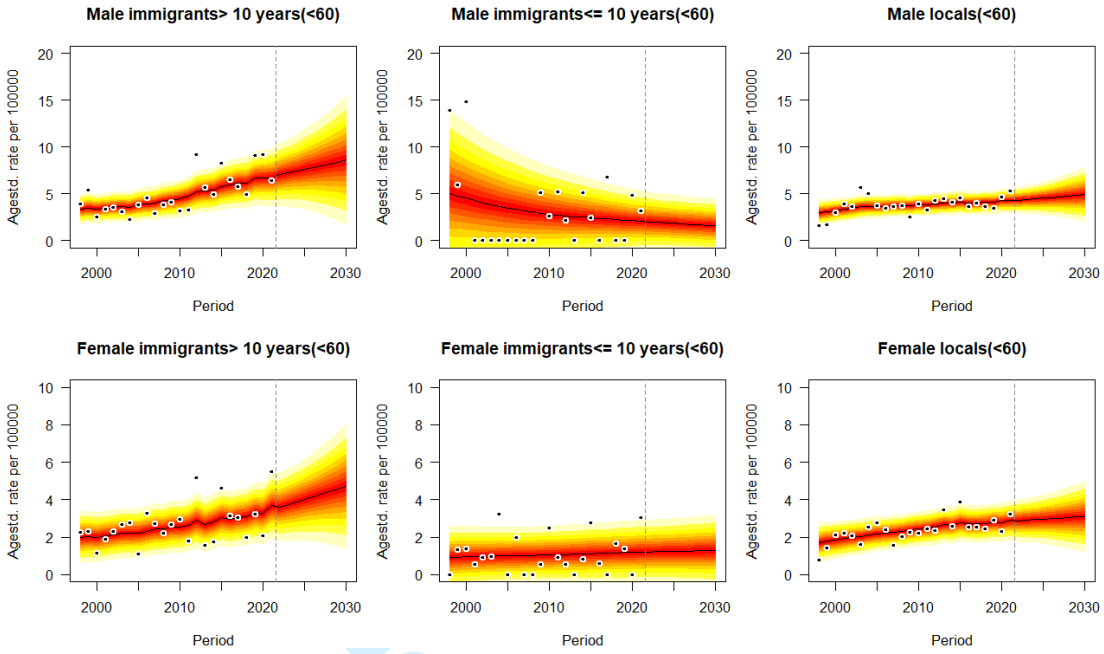
eFigure 3(b). Projections of liver cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



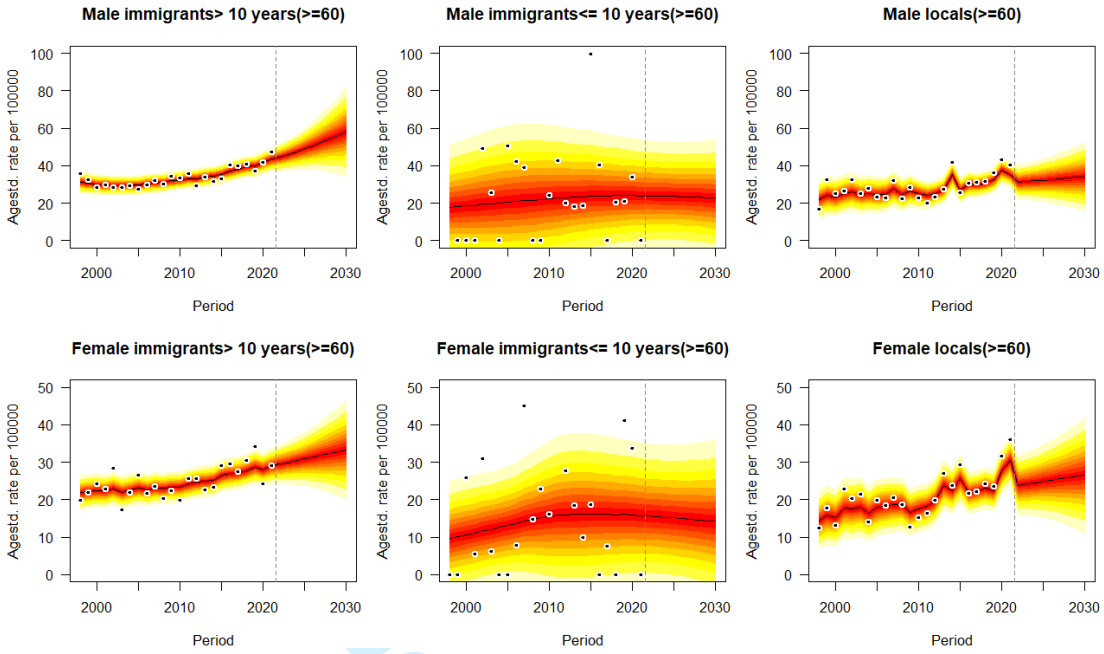
eFigure 3(c). Projections of liver cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



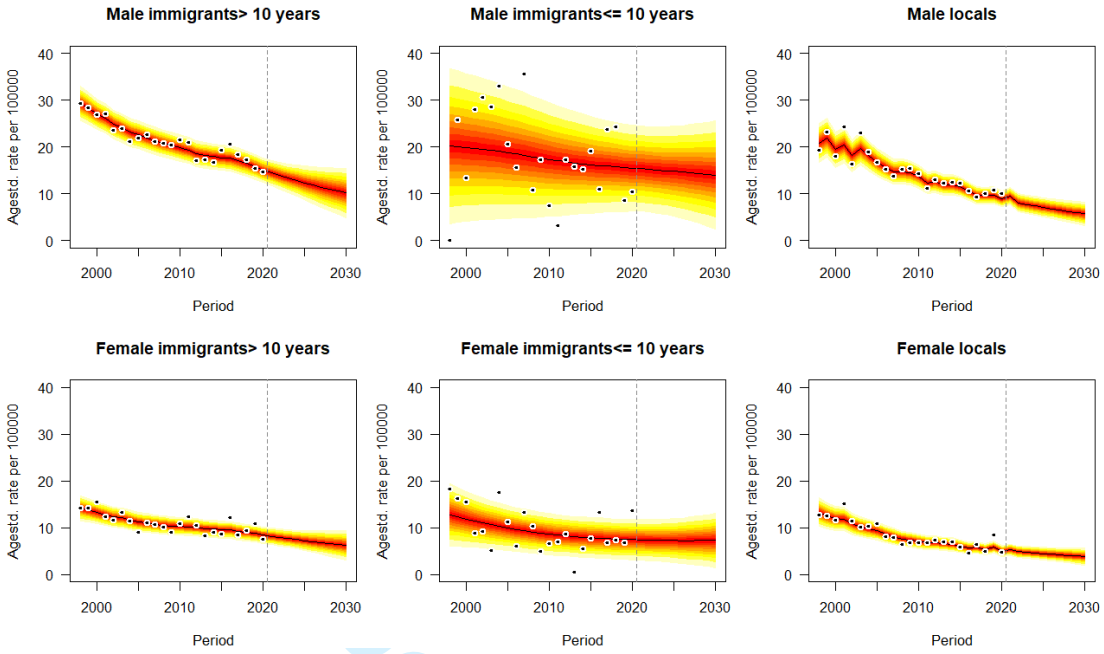
eFigure 4(a). Projections of pancreatic cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



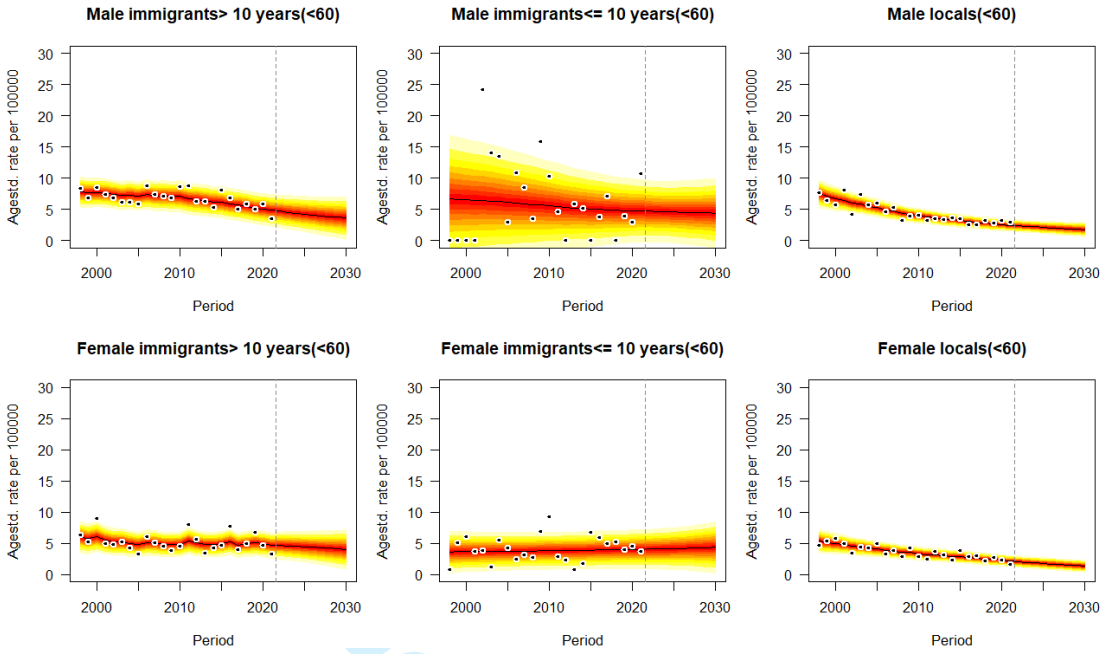
eFigure 4(b). Projections of pancreatic cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



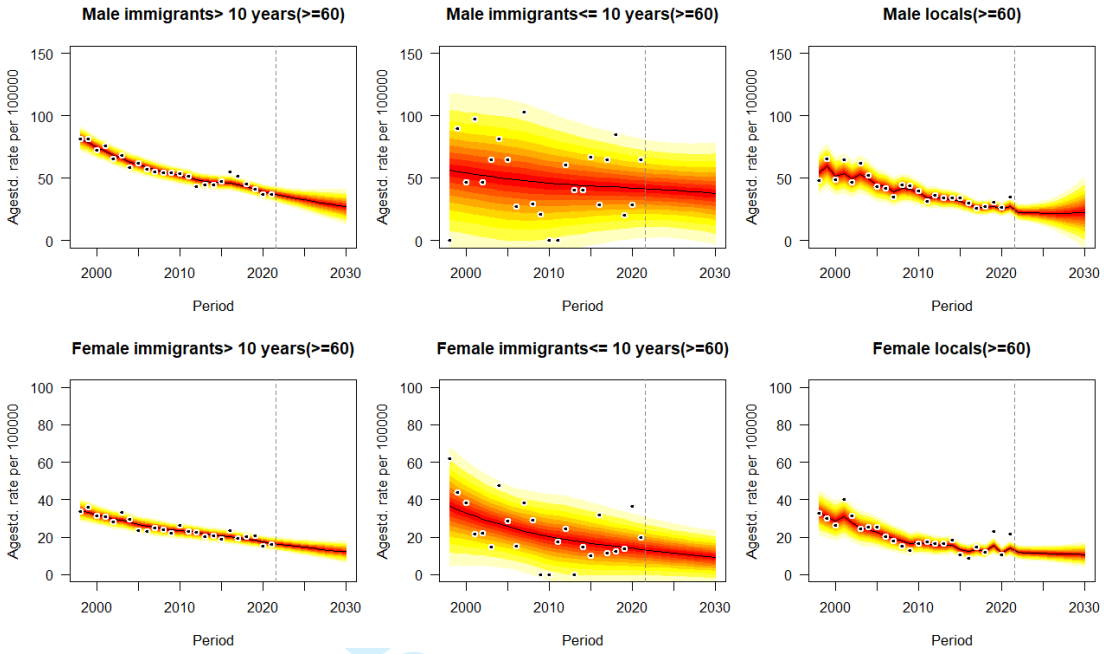
eFigure 4(c). Projections of pancreatic cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



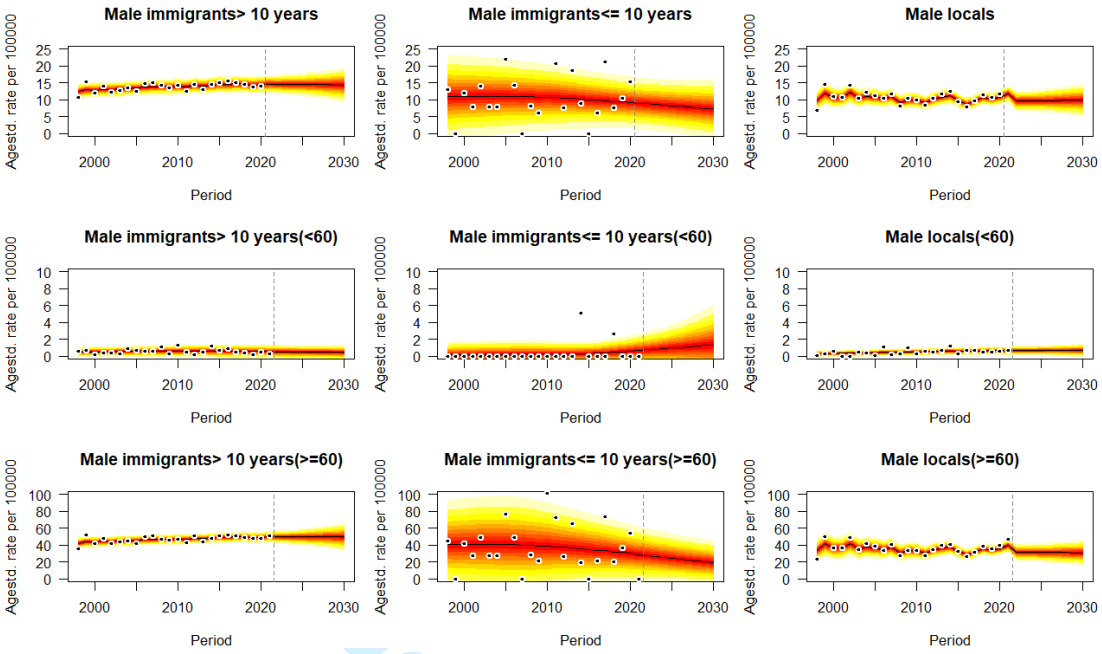
eFigure 5(a). Projections of stomach cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 5(b). Projections of stomach cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 5(c). Projections of stomach cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 6. Projections of prostate cancer mortality rates for males by immigrant status and age groups (less than, greater than or equal to 60 years old) from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Predictive mean of age-standardized mortality rates of lung cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	41.80 (1.27)	41.34 (1.86)	40.58 (2.27)	39.87 (2.75)	39.19 (3.28)	38.53 (3.86)	37.89 (4.46)	37.26 (5.09)	36.65 (5.74)	36.04 (6.4)
Female immigrants ≤ 10	23.92 (4.00)	22.22 (4.67)	20.56 (5.38)	19.01 (6.10)	17.57 (6.80)	16.24 (7.45)	15.00 (8.04)	13.85 (8.56)	12.79 (9.01)	11.81 (9.39)
Female locals	34.67 (1.76)	30.22 (3.54)	30.63 (4.77)	31.05 (6.38)	31.48 (8.29)	31.9 (10.47)	32.32 (12.87)	32.73 (15.48)	33.15 (18.31)	33.55 (21.33)
Male immigrants >10	102.90 (2.43)	100.18 (4.18)	97.18 (5.33)	94.34 (6.72)	91.71 (8.24)	89.15 (9.84)	86.66 (11.47)	84.19 (13.11)	81.81 (14.74)	79.55 (16.37)
Male immigrants ≤10	81.26 (9.21)	79.90 (10.41)	79.81 (11.82)	79.72 (13.42)	79.62 (15.19)	79.50 (17.09)	79.32 (19.09)	79.08 (21.18)	78.78 (23.32)	78.41 (25.53)
Male locals	60.96 (2.82)	52.27 (4.86)	50.83 (5.39)	49.56 (6.13)	48.18 (6.97)	46.64 (7.84)	45.13 (8.76)	43.83 (9.76)	42.67 (10.8)	41.43 (11.8)
Female immigrants>10(<60y)	15.51 (1.12)	14.51 (1.50)	13.90 (1.76)	13.29 (2.04)	12.71 (2.33)	12.13 (2.62)	11.57 (2.91)	11.02 (3.18)	10.49 (3.43)	9.98 (3.68)
Female immigrants ≤ 10(<60y)	8.14 (1.91)	7.79 (1.95)	7.18(2.23)	6.62(2.53)	6.10(2.81)	5.63(3.08)	5.19(3.32)	4.79 (3.53)	4.42 (3.72)	4.09 (3.88)
Female locals(<60y)	10.25 (0.77)	9.48 (0.89)	9.17(1.02)	8.87(1.16)	8.57(1.32)	8.27(1.49)	7.97(1.65)	7.68 (1.82)	7.38 (1.98)	7.09 (2.13)
Male immigrants>10(<60y)	27.81 (2.10)	26.36 (3.58)	24.96 (3.94)	23.64 (4.35)	22.38 (4.79)	21.17 (5.23)	20.03 (5.67)	18.96 (6.10)	17.96 (6.51)	17.03 (6.90)
Male immigrants ≤ 10(<60y)	15.01 (2.98)	13.38 (3.71)	12.02 (4.17)	10.79 (4.59)	9.68 (4.95)	8.69 (5.24)	7.79 (5.46)	6.98 (5.61)	6.25 (5.69)	5.59 (5.72)
Male locals(<60y)	15.19 (0.78)	14.45 (1.15)	14.03 (1.29)	13.61 (1.46)	13.14 (1.64)	12.65 (1.82)	12.13 (2.01)	11.55 (2.17)	10.93 (2.31)	10.26 (2.43)
Female immigrants >10(≥ 60y)	108.85 (4.80)	107.21 (5.17)	106.26 (6.24)	105.52 (7.54)	104.94 (9.04)	104.51 (10.72)	104.21 (12.57)	104.07 (14.61)	104.06 (16.78)	104.16 (19.14)
Female immigrants ≤ 10(≥60y)	66.16 (13.25)	63.84 (15.72)	59.88 (17.50)	56.14 (19.31)	52.60 (21.03)	49.27 (22.66)	46.14 (24.16)	43.20 (25.52)	40.44 (26.74)	37.85 (27.81)
Female locals(≥60y)	77.33 (9.40)	76.53 (10.11)	76.22 (10.85)	75.94 (11.79)	75.69 (12.94)	75.49 (14.28)	75.32 (15.80)	75.19 (17.48)	75.10 (19.33)	75.03 (21.32)
Male immigrants>10(≥60y)	293.56 (9.13)	289.8 (11.7)	286.6 (15.19)	284.28 (19.51)	282.78 (24.49)	281.99 (30.07)	281.88 (36.31)	282.31 (43.15)	283.37 (50.66)	285.03 (58.86)
Male immigrants ≤ 10(≥60y)	244.88 (30.29)	247.01 (36.85)	251.24 (42.94)	255.62 (50.06)	260.14 (58.14)	264.82 (67.14)	269.61 (77.01)	274.52 (87.75)	279.55 (99.34)	284.69 (111.81)
Male locals(≥60y)	150.75 (16.22)	146.29 (18.46)	143.54 (20.58)	141.84 (23.97)	140.07 (28.24)	138.14 (33.39)	136.65 (39.82)	136.49 (47.87)	137.24 (57.47)	138.26 (68.52)

eTable 1. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of lung cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of colon cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	20.03 (0.95)	18.95 (1.13)	18.77 (1.37)	18.59 (1.66)	18.42 (1.98)	18.27 (2.33)	18.12 (2.71)	17.98 (3.11)	17.85 (3.53)	17.73 (3.96)
Female immigrants ≤ 10	8.11 (2.19)	7.70 (2.51)	7.25 (2.81)	6.82 (3.11)	6.42 (3.37)	6.03 (3.61)	5.67 (3.83)	5.33 (4.01)	5.01 (4.17)	4.71 (4.31)
Female locals	13.77 (1.30)	13.47 (1.61)	13.24 (1.72)	13.01 (1.87)	12.77 (2.04)	12.53 (2.24)	12.29 (2.46)	12.06 (2.68)	11.82 (2.92)	11.59 (3.16)
Male immigrants >10	31.22 (1.28)	29.82 (1.46)	29.66 (1.79)	29.52 (2.19)	29.41 (2.63)	29.30 (3.11)	29.21 (3.64)	29.14 (4.19)	29.06 (4.78)	28.98 (5.39)
Male immigrants ≤10	15.47 (2.14)	16.77 (3.77)	17.02 (4.18)	17.23 (4.64)	17.45 (5.14)	17.67 (5.69)	17.88 (6.27)	18.09 (6.91)	18.31 (7.56)	18.50 (8.26)
Male locals	21.28 (1.38)	19.81 (2.07)	19.39 (2.22)	18.97 (2.42)	18.57 (2.61)	18.18 (2.85)	17.81 (3.12)	17.43 (3.40)	17.06 (3.71)	16.71 (4.03)
Female immigrants >10(<60y)	7.09 (0.99)	7.36 (1.12)	7.46 (1.28)	7.56 (1.46)	7.65 (1.68)	7.74 (1.92)	7.83 (2.19)	7.92 (2.48)	8.01 (2.79)	8.09 (3.13)
Female immigrants ≤ 10(<60y)	3.11 (0.67)	2.82 (0.86)	2.65 (0.91)	2.51 (0.97)	2.36 (1.02)	2.22 (1.07)	2.08 (1.11)	1.95 (1.14)	1.83 (1.18)	1.72 (1.22)
Female locals(<60y)	4.10 (0.41)	3.87 (0.50)	3.73 (0.54)	3.61 (0.59)	3.47 (0.65)	3.34 (0.70)	3.22 (0.76)	3.11 (0.82)	2.99 (0.88)	2.88 (0.94)
Male immigrants >10(<60y)	8.29 (0.91)	7.98 (1.17)	7.85 (1.38)	7.71 (1.60)	7.54 (1.83)	7.36 (2.08)	7.17(2.32)	6.97(2.57)	6.76(2.81)	6.55(3.05)
Male immigrants ≤ 10(<60y)	5.03 (1.44)	5.18 (1.58)	5.22 (1.75)	5.26 (1.93)	5.30 (2.14)	5.34 (2.36)	5.38(2.59)	5.43(2.84)	5.47(3.11)	5.51(3.38)
Male locals(<60y)	5.14 (0.43)	4.88 (0.63)	4.66 (0.79)	4.46 (0.96)	4.26 (1.13)	4.08 (1.31)	3.91(1.48)	3.73(1.65)	3.57(1.82)	3.42(1.97)
Female immigrants >10(≥60y)	52.16 (2.59)	49.21 (2.99)	48.70 (3.56)	48.26 (4.26)	47.87 (5.05)	47.54 (5.94)	47.26 (6.90)	47.05 (7.94)	46.91 (9.06)	46.81 (10.26)
Female immigrants ≤ 10(≥60y)	24.01 (5.83)	22.44 (6.56)	21.69 (6.96)	20.95 (7.38)	20.23 (7.80)	19.52 (8.23)	18.84 (8.66)	18.17 (9.08)	17.51 (9.49)	16.86 (9.90)
Female locals(≥60y)	37.42 (5.31)	36.69 (5.74)	36.29 (6.06)	35.87 (6.46)	35.46 (6.95)	35.04 (7.5)	34.61 (8.12)	34.19 (8.79)	33.77 (9.51)	33.34 (10.27)
Male immigrants >10(≥60y)	84.17 (3.55)	82.72 (4.09)	82.16 (4.95)	81.64 (5.97)	81.19 (7.12)	80.81 (8.39)	80.47 (9.77)	80.15 (11.24)	79.85 (12.81)	79.56 (14.45)
Male immigrants ≤ 10(≥60y)	43.25 (11.07)	44.93 (13.09)	45.62 (14.52)	46.30 (16.09)	46.96 (17.80)	47.61 (19.64)	48.25 (21.62)	48.88 (23.73)	49.51 (25.97)	50.13 (28.34)
Male locals(≥60y)	55.79 (6.86)	54.89 (7.65)	53.75 (8.03)	52.63 (8.52)	51.54 (9.12)	50.47 (9.8)	49.43 (10.55)	48.42 (11.37)	47.42 (12.25)	46.44 (13.16)

eTable 2. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of colon cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of liver cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	11.34 (0.66)	10.68 (0.71)	10.09 (0.85)	9.54 (1.01)	9.01 (1.16)	8.50 (1.31)	8.02(1.45)	7.57(1.59)	7.14(1.72)	6.74(1.83)
Female immigrants ≤10	9.15 (1.55)	8.66 (1.82)	8.38 (1.95)	8.11 (2.08)	7.84 (2.22)	7.58 (2.36)	7.32(2.49)	7.07(2.63)	6.82(2.76)	6.58(2.88)
Female locals	6.72 (0.69)	6.36 (0.88)	6.08 (0.90)	5.81 (0.93)	5.53 (0.97)	5.26 (1.01)	5.01(1.06)	4.77(1.11)	4.53(1.15)	4.3(1.21)
Male immigrants >10	52.17 (1.78)	49.22 (2.36)	47.76 (2.93)	46.35 (3.59)	45.01 (4.31)	43.67 (5.05)	42.37 (5.81)	41.1(6.56)	39.89 (7.33)	38.71 (8.08)
Male immigrants ≤10	42.33 (5.87)	39.03 (6.49)	37.39 (7.47)	35.81 (8.51)	34.26 (9.58)	32.76 (10.63)	31.31 (11.65)	29.91 (12.62)	28.56 (13.54)	27.25 (14.40)
Male locals	24.22 (1.77)	22.16 (2.09)	21.02 (2.22)	19.91 (2.39)	18.85 (2.58)	17.83 (2.79)	16.85 (3.03)	15.92 (3.21)	15.03 (3.40)	14.18 (3.59)
Female immigrants >10(<60y)	3.62 (0.45)	3.39 (0.52)	3.29 (0.57)	3.20 (0.63)	3.12 (0.69)	3.04 (0.75)	2.96(0.82)	2.89(0.89)	2.82(0.96)	2.75(1.03)
Female immigrants ≤ 10(<60y)	4.10 (0.79)	3.81 (0.91)	3.69 (0.96)	3.57 (1.02)	3.46 (1.08)	3.36 (1.15)	3.25(1.22)	3.15(1.29)	3.06(1.36)	2.97(1.43)
Female locals(<60y)	1.50 (0.13)	1.37 (0.2)	1.29 (0.21)	1.22 (0.23)	1.16 (0.24)	1.10 (0.26)	1.04(0.27)	0.99(0.29)	0.94(0.30)	0.89(0.31)
Male immigrants >10(<60y)	26.32 (2.11)	24.04 (2.35)	23.02 (2.63)	22.05 (2.94)	21.13 (3.27)	20.25 (3.61)	19.41 (3.95)	18.62 (4.30)	17.86 (4.64)	17.14 (4.98)
Male immigrants ≤ 10(<60y)	25.52 (2.99)	22.56 (3.96)	21.71 (4.44)	20.87 (4.94)	20.04 (5.45)	19.22 (5.95)	18.42 (6.45)	17.63 (6.91)	16.86 (7.36)	16.11 (7.78)
Male locals(<60y)	8.25 (0.69)	7.47 (0.74)	6.97 (0.79)	6.52 (0.86)	6.11 (0.93)	5.73 (1.01)	5.38(1.08)	5.04(1.15)	4.73(1.21)	4.44(1.27)
Female immigrants >10(≥ 60y)	33.67 (1.88)	29.63 (2.01)	27.99 (2.36)	26.42 (2.75)	24.92 (3.14)	23.49 (3.52)	22.13 (3.88)	20.85 (4.23)	19.64 (4.55)	18.50 (4.85)
Female immigrants ≤10(≥ 60y)	21.72 (5.11)	19.08 (5.81)	18.38 (6.14)	17.71 (6.48)	17.03 (6.83)	16.39 (7.16)	15.76 (7.49)	15.16 (7.80)	14.57 (8.11)	14.01 (8.39)
Female locals(≥60y)	20.63 (3.03)	18.41 (3.23)	17.55 (3.26)	16.72 (3.32)	15.91 (3.40)	15.11 (3.49)	14.34 (3.59)	13.59 (3.69)	12.87 (3.81)	12.17 (3.93)
Male immigrants >10(≥ 60y)	115.39 (4.54)	113.96 (5.95)	113.43 (7.65)	113.17 (9.70)	113.16 (12.04)	113.37 (14.66)	113.79 (17.56)	114.39 (20.73)	115.19 (24.18)	116.17 (27.91)
Male immigrants ≤10(≥ 60y)	88.61 (15.58)	85.14 (18.85)	82.59 (20.6)	80.02 (22.44)	77.42 (24.34)	74.83 (26.24)	72.23 (28.12)	69.64 (29.94)	67.07 (31.70)	64.52 (33.38)
Male locals(≥60y)	62.88 (5.97)	58.95 (7.91)	56.51 (8.20)	54.14 (8.61)	51.84 (9.12)	49.61 (9.70)	47.46 (10.33)	45.38 (11.01)	43.38 (11.68)	41.45 (12.36)

eTable 3. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of liver cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of pancreatic cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	10.89 (0.62)	11.11 (0.75)	11.36 (0.91)	11.61 (1.09)	11.87 (1.31)	12.14 (1.56)	12.42 (1.84)	12.71 (2.15)	13.01 (2.48)	13.3(2.85)
Female immigrants ≤ 10	5.51 (1.44)	5.44 (1.56)	5.44 (1.69)	5.43(1.84)	5.42(1.99)	5.41(2.15)	5.39(2.32)	5.36(2.49)	5.34(2.66)	5.31(2.84)
Female locals	8.79 (1.10)	9.01 (1.22)	9.15 (1.34)	9.29(1.48)	9.43(1.64)	9.57(1.83)	9.71(2.05)	9.85(2.28)	9.99(2.54)	10.14 (2.83)
Male immigrants >10	16.30 (0.98)	17.87 (1.19)	18.48 (1.49)	19.11 (1.87)	19.78 (2.32)	20.47 (2.83)	21.18 (3.42)	21.92 (4.07)	22.69 (4.81)	23.49 (5.61)
Male immigrants ≤10	8.10 (2.02)	7.87 (2.37)	7.76 (2.53)	7.64(2.70)	7.51(2.87)	7.38(3.05)	7.24(3.23)	7.09(3.41)	6.95(3.58)	6.81(3.75)
Male locals	11.97 (1.26)	12.29 (1.49)	12.49 (1.64)	12.69 (1.83)	12.91 (2.06)	13.11 (2.33)	13.33 (2.63)	13.55 (2.97)	13.78 (3.34)	14.02 (3.74)
Female immigrants >10(<60y)	3.47 (0.33)	3.62 (0.57)	3.74 (0.66)	3.87(0.77)	4.01(0.89)	4.14(1.02)	4.28(1.18)	4.42(1.34)	4.57(1.53)	4.72(1.73)
Female immigrants ≤ 10(<60y)	1.12 (0.33)	1.21 (0.48)	1.22 (0.52)	1.23(0.56)	1.24(0.61)	1.25(0.66)	1.26(0.71)	1.26(0.77)	1.27(0.83)	1.28(0.89)
Female locals(<60y)	2.76 (0.27)	2.88 (0.36)	2.91 (0.41)	2.93(0.48)	2.96(0.55)	2.99(0.63)	3.02(0.71)	3.04(0.81)	3.07(0.90)	3.10(1.01)
Male immigrants >10(<60y)	6.88 (0.98)	7.05 (1.11)	7.24 (1.32)	7.43(1.56)	7.62(1.84)	7.82(2.16)	8.01(2.50)	8.21(2.88)	8.40(3.30)	8.61(3.75)
Male immigrants ≤ 10(<60y)	2.20 (0.71)	2.01 (0.85)	1.95 (0.91)	1.9(0.94)	1.84(0.99)	1.79(1.04)	1.74(1.09)	1.69(1.14)	1.64(1.19)	1.60(1.24)
Male locals(<60y)	4.16 (0.35)	4.33 (0.48)	4.41 (0.57)	4.46(0.68)	4.53(0.81)	4.61(0.94)	4.69(1.09)	4.77(1.26)	4.85(1.44)	4.93(1.63)
Female immigrants >10(≥60y)	28.58 (1.83)	29.45 (2.11)	29.91 (2.54)	30.38 (3.06)	30.85 (3.66)	31.33 (4.33)	31.81 (5.08)	32.29 (5.91)	32.78 (6.79)	33.27 (7.74)
Female immigrants ≤ 10(≥60y)	16.79 (5.29)	15.65 (6.08)	15.49 (6.71)	15.33 (7.36)	15.16 (8.03)	14.97 (8.73)	14.79 (9.43)	14.59 (10.14)	14.39 (10.86)	14.19 (11.58)
Female locals(≥60y)	22.80 (4.23)	23.85 (4.46)	24.21 (4.81)	24.56 (5.23)	24.91 (5.73)	25.25 (6.30)	25.58 (6.95)	25.90 (7.67)	26.22 (8.47)	26.54 (9.34)
Male immigrants >10(≥60y)	42.70 (2.55)	44.36 (3.02)	45.85 (3.76)	47.41 (4.69)	49.04 (5.78)	50.73 (7.05)	52.48 (8.50)	54.28 (10.13)	56.16 (11.95)	58.11 (13.98)
Male immigrants ≤ 10(≥60y)	24.68 (8.21)	23.96 (9.01)	23.87 (9.74)	23.75 (10.52)	23.61 (11.33)	23.45 (12.17)	23.28 (13.04)	23.09 (13.93)	22.89 (14.83)	22.68 (15.75)
Male locals(≥60y)	30.10 (4.68)	31.17 (5.22)	31.55 (5.63)	31.93 (6.14)	32.30 (6.75)	32.66 (7.45)	33.01 (8.23)	33.35 (9.11)	33.69 (10.08)	34.03 (11.12)

eTable 4. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of pancreatic cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of stomach cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	8.20 (0.55)	7.95 (0.62)	7.71 (0.74)	7.47 (0.87)	7.25 (1.01)	7.03 (1.15)	6.83 (1.29)	6.62 (1.43)	6.43 (1.57)	6.24 (1.71)
Female immigrants ≤ 10	7.51 (1.44)	7.36 (1.56)	7.33 (1.69)	7.30 (1.85)	7.28 (2.01)	7.27 (2.20)	7.27 (2.40)	7.28 (2.61)	7.31 (2.84)	7.33 (3.09)
Female locals	5.26 (0.40)	4.91 (0.52)	4.75 (0.57)	4.61 (0.63)	4.47 (0.71)	4.34 (0.77)	4.21 (0.84)	4.08 (0.91)	3.95 (0.99)	3.83 (1.06)
Male immigrants >10	15.22 (0.64)	13.89 (0.97)	13.34(1.21)	12.81 (1.46)	12.31 (1.73)	11.83 (1.99)	11.38 (2.26)	10.95 (2.51)	10.54 (2.76)	10.15 (3.01)
Male immigrants ≤10	15.83 (3.04)	15.21 (3.38)	15.07 (3.67)	14.93 (3.98)	14.79 (4.31)	14.64 (4.65)	14.51 (5.02)	14.35 (5.39)	14.19 (5.78)	14.03 (6.17)
Male locals	8.14 (0.89)	8.07 (0.99)	7.73 (1.03)	7.41(1.07)	7.10 (1.13)	6.81 (1.19)	6.51 (1.26)	6.23 (1.33)	5.97 (1.39)	5.71 (1.46)
Female immigrants >10(<60y)	4.81 (0.56)	4.69 (0.79)	4.62 (0.87)	4.55 (0.96)	4.47 (1.07)	4.39 (1.17)	4.31 (1.29)	4.22 (1.41)	4.13 (1.52)	4.03 (1.64)
Female immigrants ≤ 10(<60y)	3.89 (0.80)	4.08 (0.93)	4.10 (1.03)	4.13 (1.14)	4.17 (1.27)	4.21 (1.41)	4.24 (1.55)	4.28 (1.70)	4.32 (1.87)	4.36 (2.05)
Female locals(<60y)	2.28 (0.21)	2.08 (0.27)	1.98 (0.29)	1.88 (0.32)	1.79 (0.35)	1.71 (0.37)	1.61 (0.41)	1.53 (0.43)	1.44 (0.45)	1.37 (0.47)
Male immigrants >10(<60y)	4.94 (0.57)	4.71 (0.79)	4.55 (0.89)	4.41 (0.99)	4.25 (1.10)	4.12 (1.21)	3.98 (1.32)	3.86 (1.43)	3.74 (1.54)	3.63 (1.65)
Male immigrants ≤ 10(<60y)	4.81 (1.31)	4.70 (1.42)	4.66 (1.55)	4.63 (1.69)	4.59 (1.83)	4.55 (1.99)	4.52 (2.15)	4.48 (2.32)	4.44 (2.50)	4.41 (2.68)
Male locals(<60y)	2.48 (0.21)	2.37 (0.29)	2.28 (0.32)	2.21 (0.35)	2.12 (0.38)	2.04 (0.42)	1.97 (0.45)	1.91 (0.49)	1.83 (0.52)	1.77(0.55)
Female immigrants >10(≥60y)	17.80 (1.04)	16.23 (1.26)	15.65 (1.47)	15.08 (1.70)	14.55 (1.94)	14.03 (2.18)	13.54 (2.43)	13.07 (2.68)	12.62 (2.92)	12.19 (3.16)
Female immigrants ≤ 10(≥60y)	14.72 (4.29)	13.01 (4.83)	12.52 (5.11)	12.03 (5.37)	11.55 (5.63)	11.08 (5.88)	10.63 (6.12)	10.19 (6.35)	9.76(6.56)	9.34 (6.75)
Female locals(≥60y)	12.20 (1.66)	11.86 (1.84)	11.67 (1.98)	11.49 (2.15)	11.33 (2.35)	11.18 (2.58)	11.04 (2.84)	10.91 (3.11)	10.79(3.4)	10.68 (3.71)
Male immigrants >10(≥60y)	37.23 (2.29)	36.59 (2.56)	35.17(3.18)	33.82 (3.86)	32.55 (4.57)	31.34 (5.28)	30.19 (6.01)	29.08 (6.70)	28.02 (7.40)	27.01 (8.07)
Male immigrants ≤ 10(≥60y)	42.30 (10.88)	41.43 (11.78)	41.03 (12.71)	40.61 (13.70)	40.17 (14.75)	39.71 (15.85)	39.24 (16.99)	38.75 (18.16)	38.23 (19.35)	37.71 (20.57)
Male locals(≥60y)	23.04 (3.29)	22.69 (3.56)	22.37(4.07)	22.16(4.84)	21.89 (5.86)	21.61 (7.22)	21.52 (9.02)	21.74 (11.29)	22.17 (14.03)	22.73 (17.28)

eTable 5. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of stomach cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of prostate cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Male immigrants >10	14.81 (0.61)	14.59 (0.79)	14.57 (0.96)	14.56 (1.15)	14.54 (1.37)	14.51 (1.61)	14.48 (1.86)	14.45 (2.13)	14.42 (2.42)	14.38 (2.72)
Male immigrants ≤10	9.03 (2.95)	8.78 (3.11)	8.58 (3.29)	8.39 (3.49)	8.19(3.69)	8.10(3.89)	7.82(4.11)	7.63(4.31)	7.45(4.51)	7.27(4.72)
Male locals	9.54 (1.40)	9.66 (1.57)	9.67 (1.66)	9.69 (1.77)	9.72(1.91)	9.75(2.06)	9.78(2.23)	9.82(2.43)	9.86(2.64)	9.9(2.88)
Male immigrants >10(<60y)	0.57 (0.12)	0.52 (0.17)	0.51 (0.19)	0.50 (0.21)	0.49(0.22)	0.48(0.24)	0.47(0.25)	0.46(0.27)	0.45(0.29)	0.44(0.31)
Male immigrants ≤ 10(<60y)	0.65 (0.59)	0.73 (0.77)	0.81 (0.93)	0.87 (1.10)	0.94(1.31)	1.01(1.51)	1.09(1.75)	1.16(2.02)	1.24(2.32)	1.33(2.64)
Male locals(<60y)	0.63 (0.12)	0.66 (0.14)	0.66 (0.16)	0.66 (0.19)	0.67(0.21)	0.67(0.24)	0.67(0.27)	0.68(0.31)	0.68(0.33)	0.69(0.37)
Male immigrants >10(≥ 60y)	49.43 (2.59)	49.61 (2.73)	49.63 (3.29)	49.64 (3.94)	49.64 (4.68)	49.64 (5.51)	49.63 (6.38)	49.62 (7.32)	49.61 (8.32)	49.58(9.37)
Male immigrants ≤ 10(≥60y)	28.29 (9.15)	27.66 (9.78)	26.53 (10.21)	25.4 (10.63)	24.28 (11.03)	23.16 (11.41)	22.07 (11.76)	21.01 (12.09)	19.96 (12.38)	18.95(12.63)
Male locals(≥60y)	31.57 (5.17)	31.48 (5.49)	31.40 (5.76)	31.32 (6.09)	31.24 (6.48)	31.15 (6.94)	31.06 (7.44)	30.96 (8.01)	30.86 (8.61)	30.74(9.26)

eTable 6. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of prostate cancer per 100,000 population for each age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Reporting checklist for cohort study.

Based on the STROBE cohort guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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In your methods section, say that you used the STROBE cohortreporting guidelines, and cite them as:

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		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	5
Setting	#5	Describe the setting, locations, and relevant dates, including periods	5

		of recruitment, exposure, follow-up, and data collection	
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up.	5
Eligibility criteria	#6b	For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5
Bias	#9	Describe any efforts to address potential sources of bias	5
Study size	#10	Explain how the study size was arrived at	5
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	5
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	5
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	5
Statistical methods	#12c	Explain how missing data were addressed	5
Statistical methods	#12d	If applicable, explain how loss to follow-up was addressed	n/a
Statistical methods	#12e	Describe any sensitivity analyses	n/a
Results			
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible,	n/a

		included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	5
Participants	#13c	Consider use of a flow diagram	
n/a			
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	5
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	
n/a			
Descriptive data	#14c	Summarise follow-up time (eg, average and total amount)	
n/a			
Outcome data	#15	Report numbers of outcome events or summary measures over time. Give information separately for exposed and unexposed groups if applicable.	
n/a			
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6
Main results	#16b	Report category boundaries when continuous variables were categorized	n/a
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
n/a			
Other analyses	#17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	7

Discussion

Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	10
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

This checklist was completed on 11. February 2023 using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai

BMJ Open

An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030

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Abstract

Objectives: To explore the relationship between immigration groups and cancer mortality, this study aimed to explore age, period, birth cohort effects and effects across genders and immigration groups on mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers and their projections.

Design, setting, and participants: Death registry data in Hong Kong between 1998 and 2021, which were stratified by age, sex and immigration status. Immigration status was classified into three groups: locals born in Hong Kong, long-stay immigrants and short-stay immigrants.

Methods: Age-period-cohort analysis was used to examine age, period, and birth cohort effects for genders and immigration groups from 1998 to 2021. Bayesian age-period-cohort models were applied to predict the mortality rates from 2022 to 2030.

Results: Short-stay immigrants revealed pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Immigrants for each type of cancer and gender will be at a higher mortality risk than locals. After 2021, decreasing trends ($p<0.05$) or plateau ($p>0.05$) of forecasting mortality rates of cancers occur for all immigration groups, except for increasing trends for short-stay male immigrants with colon cancer ($p<0.05$, Avg +0.30 deaths/100,000 per annum from 15.47 to 18.50 deaths/100,000) and long-stay male immigrants with pancreatic cancer ($p<0.05$, Avg +0.72 deaths/100,000 per annum from 16.30 to 23.49 deaths/100,000).,

Conclusions: Findings underscore the effect of gender and immigration status in Hong Kong on mortality risks of cancers that immigrants for each type of cancer and gender will be at a higher mortality risk than locals.

Keywords: Age-period-cohort analysis, immigration, mortality, lung cancer, pancreatic cancer, colon cancer, liver cancer, prostate cancer, stomach cancer

Strengths and limitations of this study

- This study provides new evidence regarding the relationship between immigration status and cancer mortality, given the effects of age, period, birth cohort and their predictions.
- The non-identifiability problem has not been interpreted in age-period-cohort models.
- The future perspective of cancer therapies and techniques have not been considered.

Introduction

Several migration waves from mainland China to Hong Kong have occurred over the past century. These migration waves included a large-scale migration inflow from 1945 to 1950 (the Chinese Civil War) and a few small-scale inflows in the 1950s, 1970s, and 1990s [1-3]. In 2016, immigrants from mainland China formed approximately 38% of the population of Hong Kong. These inflows have led to a growing interest in research on the disparity of health conditions between the locals and immigrants.

Cancer has been one of the most common causes of death, as an estimated 19.3 million new cancer cases and 9.9 million new cancer-associated deaths occurred worldwide in 2020 [4]. In Hong Kong, lung cancer is one of the most common causes of cancer deaths [5, 6]. Previous studies suggested that the primary cause of lung cancer is cigarette smoking [7-11]. Genetic factors, asbestos, radon gas, second-hand smoke, and other forms of air pollution have been proven to influence the risk of lung cancer [12-18]. The overall daily smoking rate in mainland China was approximately 23.2% in 2018 [19], whereas the daily smoking rate in Hong Kong was only 10.2% in 2019 [20]. The leading causes of liver cancer include viral infection, drinking of alcohol and polluted water and food supplies which are also culprits for colon, stomach and pancreatic cancer [21]. Alcohol consumption per capita in Hong Kong has reached 2.37 liters in 2021 [22], compared to 7.0 liters of per capita consumption of alcohol in mainland China in 2018 [23]. As approximately 99% of prostate cancer cases occur after age 50, factors of prostate cancer have been regarded as old age, race, family history and the diet of red meat consumption [24]. In addition to these risk factors, studies have suggested that cancer mortality rates vary depending on migrant status [25-28]. According to data from the Census and Statistics Department of Hong Kong, approximately 81% of immigrants in Hong Kong immigrated from mainland China, Macau, and Taiwan. Immigrants from mainland China account for the bulk of this population. Previous studies have shown that child immigrants in Hong Kong tend to suffer from a higher risk of wheezing disorders and cardiovascular diseases, and immigrant women have higher age-specific mortality rates of breast cancer than locally-born women in Hong Kong [29, 30]. However, to date, few studies have investigated the effect of length of stay in Hong Kong and birthplace on the risk of other types of cancer.

In this study, we compared the mortality rates of lung, pancreatic, colon, liver, prostate and stomach cancers between locally born residents in Hong Kong and immigrants from mainland China. Both populations are widely considered as ethnically homogeneous with similar cultures. Nevertheless, due to different early life experiences, immigrants are exposed to more various social economy and lifestyles than locals. Therefore, it's constructive to ascertain whether immigrants from mainland China have a different mortality pattern of cancers from locals to verify the significance of migration status for this health outcome. As age-period-cohort (APC)

analysis plays a vital role in studying time-specific phenomena in epidemiology, in this study, to evaluate the effect of immigration on cancer mortality in the past and future, we developed APC models specified by sex and migrant status to assess the effects of age, period, birth cohort, and of the length of stay in Hong Kong on the mortality risks of cancers. Additionally, we explore the projection of mortality rates for the locally born population and immigrants in Hong Kong who were younger or older than 60 using a predictive model, taking into account age, period, and birth cohort effects as well.

Methods

Data

We obtained the death registry data in Hong Kong between 1998 and 2021 from the Census and Statistics Department of Hong Kong, as the data in 2022 has not been available up to now. The data was extracted from a routine census held by the Hong Kong government as subjective errors caused by resampling can be neglected. The population data were stratified by age, sex, immigration status, and length of stay in Hong Kong. We retrieved six types of cancer cases from the death registry data using ICD codes, such as ICD-9 code 162 and ICD-10 codes C34.0–C34.3, C348, and C349 for lung cancer. To assure comparability among registries, deaths from the age group of 35–85 years were selected, since cases younger than 35 and older than 85 were relatively trivial for lack of statistical interpretability [31]. Immigration status was classified into three groups: locals born in Hong Kong, immigrants who have lived in Hong Kong for >10 years before death defined as long-stay immigrants, and immigrants who have lived in Hong Kong for ≤10 years before death defined as short-stay immigrants. Notably, much focus was placed on immigrants from mainland China, because approximately 81% of immigrants in Hong Kong came from mainland China, Macau, and Taiwan based on the data from the Census and Statistics Department of Hong Kong. Moreover, few cases recorded from Macau and Taiwan are statistically insignificant in the analysis. Demographics and population projections from 2022 to 2030 were retrieved from the Census and Statistics Department of Hong Kong and estimated with cubic smoothing spline as the prerequisite of the predictive model. Codes for APC and BAPC analysis are available in the GitHub repository (https://github.com/kshz2164313/APC-population-projections-for-immigration-HK).

Statistical analysis

We modeled cancer mortality rates in Hong Kong using APC analysis based on log-linear Poisson regression models. The model aimed to disentangle age, period, and cohort effects of time-varying phenomena simultaneously [32, 33], given that

$$\log(E_{ij}) = \alpha_i + \beta_j + \gamma_k + \mu + \log(\theta_{ij}) \quad (1)$$

where E_{ij} denotes expected mortality; α_i, β_j, and γ_k denote age, period, and cohort effect, respectively, for $i=1,...,I$, $j=1,...,J$, $k=1,...,K$ with $k=I-i+j$. $\log(\theta_{ij})$ is the offset. We mainly focused on the contributions of sex and immigration status due to the non-identifiability problem that the effects of these three components are collinear with each other (denoted as period – age = cohort) [34]. Birth cohort effect and period effect were assessed with relative risks to evaluate the effect of three components. The median year of birth among cases was regarded as the reference cohort [35,36]. Since death cases aged at 35–85 years between 1998 and 2021 were selected, the range of birth cohort from 1913 to 1986 covered observations and further projections until 2030. The second and penultimate period effects were constrained to the reference for period. For sex and immigration status, maximum likelihood framework was applied to estimate the relative risks and 95% confidence intervals (CIs) by age groups, calendar period, and birth cohort.

Several projection approaches for future cancer mortality have been developed, but a Bayesian age-period-cohort (BAPC) model built upon integrated nested Laplace approximations (INLA) [37] yields relatively higher coverage and better performance for all evaluated parameter combinations [38]. To prevent some sampling problems caused by Markov chain Monte Carlo (MCMC), this MCMC-free BAPC approach was applied to predict future cancer mortality within a fully Bayesian inference setting and provide outputs of interest simply, such as projected age-standardized and age-specific rates. Convergence checks are not necessary for this technique [37]. The projections of age-standardized cancer mortality rates for each sex, age group (younger or older than 60 years) and migrant status, taking into account age, period, and birth cohort effects, were performed based on the weights of population age groups from the WHO World Standard population [39], with 95% prediction intervals. Mann-Kendall trend test was applied to verify the projection trend. Friedman's Two-Way Analysis of Variance was applied to test interactions between gender and immigration groups for each year.

All analyses were performed via R version 4.2.1 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria, 2013, http://www.R-project.org/). The APC models were established using the Epi package, and the projections based on Bayesian APC models were performed with the BAPC package.

Patient and public involvement

None.

Results

Figure 1 & 2 and eFigure 1(a-e) in **Supplementary Material** illustrate the estimates of age (assessed by cancer mortality), cohort and period effects (assessed by relative risk) based on APC models among three migrant groups for men and women with six types of cancers,

respectively. All the mortality rates for each gender and immigration status exhibit notable increasing trends with age. Age, cohort and period effects of six types of cancer for immigrants who stayed in Hong Kong for ≤10 years revealed relatively more pronounced fluctuations and deviations from those effects in the other two immigration groups. Significant increasing trends of age effect occurred in all types of cancer, regardless of gender and immigration status. For example, while relatively insignificant differences in lung cancer mortality rates by immigration status among females have performed, male immigrants who remained in Hong Kong for >10 years had higher lung cancer mortality rates at ages above 50 years and those who arrived ≤10 years had lower lung cancer mortality at ages below 62 years compared to local men Figure 1. In addition to compatible dynamics of period effect for locals and long-stay immigrants, similar changes of relative risks by birth cohort for locals and long-stay immigrants in lung, colon, liver and stomach cancers occurred before 1945, whereas significant differences of relative risks by birth cohort between these two immigration groups occurred after 1960 (Figure 1 & eFigure 1(a,b,d)). Locals and long-stay immigrants in pancreatic and prostate cancer perform almost similar changes of relative risks by birth cohort effects all the time (eFigure 1(c,e)). Short-stay immigrants who have stayed in Hong Kong for ≤10 years had more fluctuating relative risks affected by period effects before 2020 than those for locals and long-stay immigrants. Lack of young cases, especially young short-stay immigrants, of prostate cancer leads to significant deviations and variances in age and cohort effects.

Figure 3-5, eFigure 2-6 in **Supplementary Material** illustrate the age-standardized mortality rates of six types of cancer from 1998 to 2021 and their projections by sex, immigrant status and age groups from 2022 to 2030, taking into account age, period, and birth cohort effects. Means and standard deviations of predictive mortality rates are shown in eTable 1-6 in **Supplementary Material**. For all ages projection (Figure 2 & eFigure 2-6), as approximately significant interactions between gender and immigration groups emerge for each type of cancer in each year ($p<0.05$), given the projected trends, immigrants for each gender, especially who have stayed in Hong Kong for > 10 years will suffer from higher mortality rates of cancer in each year than locals. Monotone decreasing trends or plateau of forecasting occur for both genders and all immigration groups in cancers, except for increasing trends for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer ($p < 0.05$, Avg +0.30 deaths/100,000 per annum) from 15.47 deaths/100,000 (95% CI: 11.28, 19.66) in 2021 to 18.50 deaths/100,000 (95% CI: 2.31, 34.69) in 2030, and male immigrants who have stayed in Hong Kong for > 10 years with pancreatic cancer ($p < 0.05$, Avg +0.72 deaths/100,000 per annum) from 16.30 deaths/100,000 (95% CI: 14.38,17.26) in 2021 to 23.49 deaths/100,000 (95% CI: 12.49, 34.49) in 2030. Most of predictive trends for younger cases (<60 years) and older cases (≥60 years) reach a consensus with those for all ages population, except for two phenomena: 1.) mortality rates of lung cancer for men immigrants ≤10 that insignificant trend for all ages

($p > 0.05$) vs. decline for younger cases ($p < 0.05$) vs. increase for older cases ($p < 0.05$); 2.) mortality rates of liver cancer for men immigrants >10 that decline for all ages ($p < 0.05$) vs. decline for younger cases ($p < 0.05$) vs. insignificant trend for older cases ($p > 0.05$). Some particular cases occur in the projection of prostate cancer that young long-stay male immigrants (0.44 deaths/100,000, 95% CI: 0, 1.05) aged less than 60 will be at lower mortality rate than locals (0.69 deaths/100,000, 95% CI: 0, 1.42) in 2030 (eTable 6). Compared with other cancers and immigration groups, male immigrants who have stayed in Hong Kong for >10 years with lung cancer would perform the most significant decline in predictive mean from 102.90 (95% CI: 98.14, 107.66) to 79.55 (95% CI: 47.46, 111.64) deaths per 100,000 population (Avg -2.34 deaths/100,000 per annum) (eTable 1), while the same immigration group with pancreatic cancer would indicate the most significant uptrend in each year of 16.30 (95% CI: 14.38,17.26) and 23.49 (95% CI: 12.49, 34.49) deaths per 100,000 population in 2021 and 2030, respectively (Avg +0.72 deaths/100,000 per annum) (eTable 4).

Discussion

Early detection of cancer is positive and instructive for increasing chances of cure. Nevertheless, the high mortality rate of cancer results from late diagnosis among most patients after progression to more advanced or severe stages. Individuals at high risk of cancer, such as smokers, alcoholics or those who are frequently exposed to susceptible circumstances, should be screened for early detections to increase opportunities for cure [40]. Therefore, the differences in mortality rates among immigration groups are synonymous with detection means, therapies, and social history in disparate periods and areas.

While the changes in mortality rates by age for long-stay immigrants reached approximate harmony with those for locals, the changes in mortality rates by age for short-stay immigrants revealed clear differences with those for the other two populations. The group of long-stay immigrants had a higher risk of death from lung, colon and liver cancers than the other two immigration groups after the age of 60 years. Short-stay male immigrants were less likely to die from lung cancer before the age of 65 years. The contrast in age effects among the immigration groups was partially consistent with studies [25, 41] that highlighted the age effects for locals and immigrants on breast cancer mortality in Hong Kong and lung cancer incidence in Sweden, as they both showed similar trends and magnitudes between locals and immigrants before the age of 60 years. They are also compatible with the results in [42] that diagnosis of liver cancer is the most frequent among populations at 55 to 65 years old. According to these trends, young individuals, especially new young immigrant men, who have benefited from all-rounded development in mainland China and Hong Kong, are more

likely to seek early detection and be treated for cancers using more advanced treatments [43]. Differences in birth cohort effects among immigrant groups partially comply with the interpretation above.

We observed significant trends of cohort effects among locals and immigrants. These findings are partially consistent but subtly different from previous findings, regarding the effect of immigration status on cancers. Zhao et al. [25] described multiple peaks of cohort effects on breast cancer mortality between locals and immigrants in Hong Kong, as well as a significant decline in cohort effects after 1950. In contrast, Sung et al. [44] investigated the difference in breast cancer incidence between Chinese Americans and non-Hispanic whites in the U.S. and emphasized that Chinese Americans were at lower risk of breast cancer than non-Hispanic whites born in the same year. Here, we interpret the cohort-driven trends resulting from the intricacy of social history and lifestyle. Compared to a relatively stable social development in Hong Kong, representing downward trends of relative risks for locals, wars and social instability in mainland China resulted in several immigration waves from mainland China to Hong Kong before 1950. Additionally, remarkable increasing trends were recorded for new immigrants after 1950, which corresponded to the economic downturn after wars and famine between 1959 and 1961 during their youth [45]. The increasing trends for new immigrants and similar trends for locals and long-stay immigrants were consistent with the finding that nutrient deficiency contributes to a higher risk of severe mortality rates of cancers [46]. Furthermore, we speculate that these trends, especially those for locals and long-stay immigrants, are most likely attributed to social development and personal behaviors, such as daily habits, occupational history, different diagnoses and treatments, and domestic environmental exposures. Notably, short-stay immigrants suffered from a lower risk of death from colon cancer for all ages (eFigure 1a in **Supplementary Material**). As locals and immigrants in Hong Kong transitioned to more westernized lifestyles, higher consumption of meat was associated with a higher risk of these types of cancer, whereas consumption of vegetables had a strong protective effect against pancreatic cancer, and moderate consumption of coffee appeared to be beneficial against lung cancer [47,48]. Further studies on potential risk factors are required.

Short-stay immigrants had more fluctuating and non-stationary but inconspicuous relative risks by period effects before 2021 than locals and long-stay immigrants. Cumulatively, an arch pattern and fluctuating curve depicting period effects externally resulted in an arch pattern of age-standardized mortality rates for short-stay immigrant women and irregular rates for short-stay immigrant men before 2021. The external performance of different period effects on mortality rates could be most likely attributed to the higher effect of different lifestyles and social development on new immigrants than on long-stay immigrants and locals in Hong Kong. For the age-standardized mortality rates and projections, consistent with

previous findings [49,50], we predict that the mortality rates of cancer in Hong Kong after 2021 will continue to decline or remain relatively stable, consistent with the trends before 2020, except for male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer. Men will be at higher risk of mortality rates of cancer than women, regardless of immigration status. They are also compatible with the results in [4] that men suffer from a higher risk of these types of cancer than women, excluding prostate cancer. Furthermore, new immigrant women will be at lower risk than local women, even though long-stay immigrants will suffer from higher mortality rates than locals in the future. Potential interpretations could be consistent with those for birth cohort effects, as age and period effects are considered as confounders of cohort effect.

In the past few decades, spurred by an increasing burden of high incidence and mortality rates of cancer, several studies focused on the inherent identification dilemma of three effects in the APC model. Further, complicated population distribution and immigration status in Hong Kong, one of the areas with the highest population density and migration frequency in the world, have intricate causes and inherent dynamics of cancer and other diseases. To our knowledge, few studies have assessed the relationship between immigration status and cancer mortality. Therefore, this study is original to examine the effect of the length of stay in Hong Kong and origins of previous residence on cancer deaths, which is instructive for further immigration policy-making and targeted strategies of disease detection and intervention. However, this study had several limitations. Given the non-identifiability problem in age-period-cohort models, we could only depict trends and variations among different immigration and sex groups, as illustrated in figures, and insufficiently perform the estimates of the contributions of three effects or subgroups to mortality rates. Furthermore, we adopted a cubic smoothing spline to estimate populations of immigrants and locals due to the large proportion of unspecified immigration status from official demographic projections. A few acceptable cases resulted in a limited type of cancer so that some common cancers, such as the ovary and cervix, were discarded. Since the issue of quantification, the future perspective of cancer therapies and techniques have not been considered in the model of projection.

Conclusion

We conclude that immigrants, especially short-stay immigrants, had more pronounced fluctuations of mortality rates by age and of relative risks by cohort and period effects for six types of cancers than those of long-stay immigrants and locals. Male immigrants who have stayed in Hong Kong for ≤10 years with colon cancer and male immigrants who have stayed in Hong Kong for >10 years with pancreatic cancer would perform significant uptrend in the

future, while other immigration groups for each type of cancer would continue to decline or remain relatively stable. Immigrants for each gender in Hong Kong would suffer from higher mortality risks of cancers than locals in the future.

Declaration

Ethical approval and consent to participate

Ethical approval and consent to participate are not applicable. This study does not directly involve human participants. Data was obtained from the Census and Statistics Department of Hong Kong.

Consent for publication

Not applicable.

Data availability statement

Data are available upon reasonable request.

Contributors

Yanji Zhao: Methodology, Formal analysis, Data Curation, Writing - Original Draft, Visualization. Zian Zhuang: Methodology, Formal analysis, Data Curation, Writing - Review & Editing. Lin Yang: Validation, Writing - Review & Editing. Daihai He: Conceptualization, Writing - Review & Editing, Supervision

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Competing interests

None declared.

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FIGURE LEGENDS

Figure 1. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

Figure 2. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of female lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

Figure 3. Projections of lung cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 4. Projections of lung cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Figure 5. Projections of lung cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

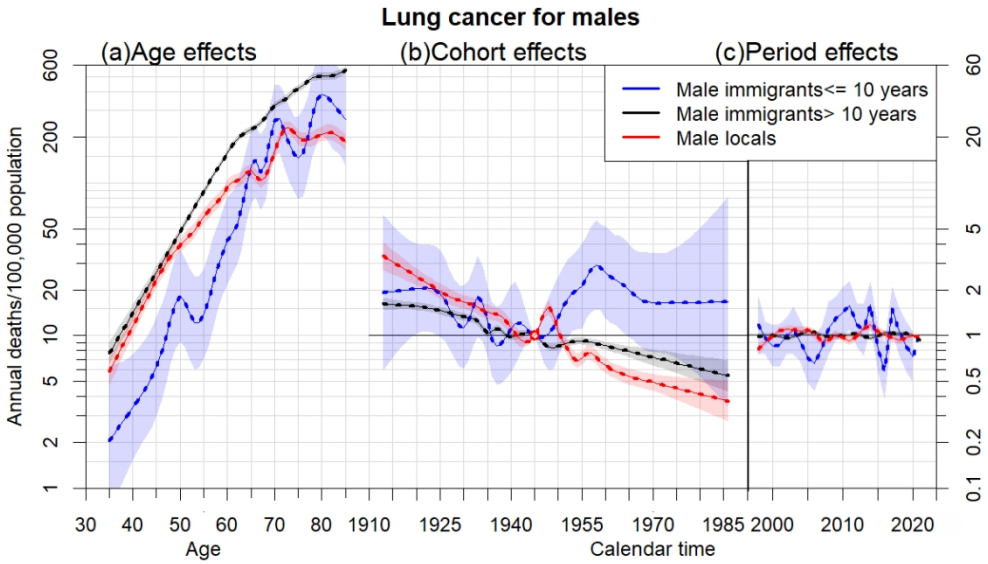

Figure 1. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

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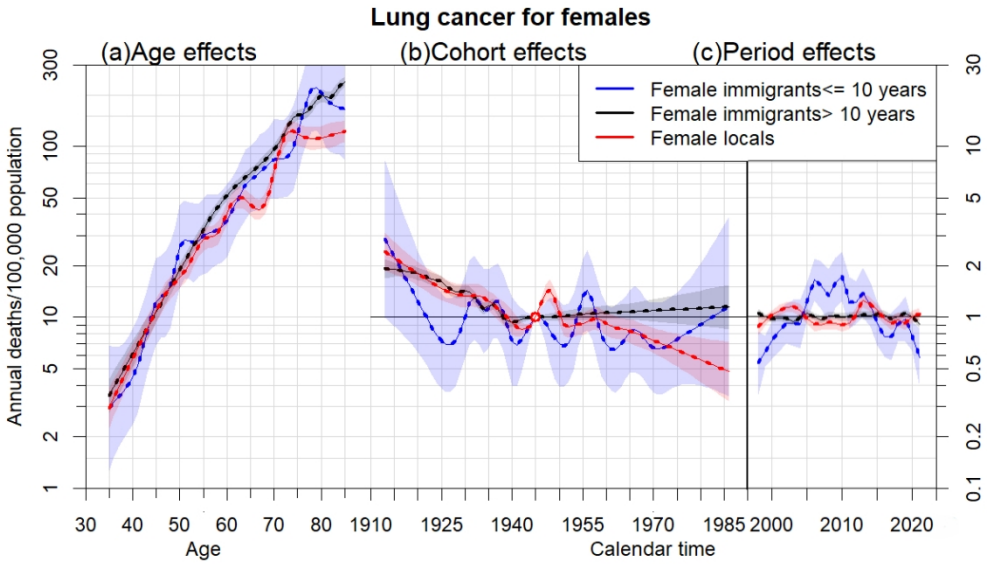

Figure 2. Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of female lung cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.

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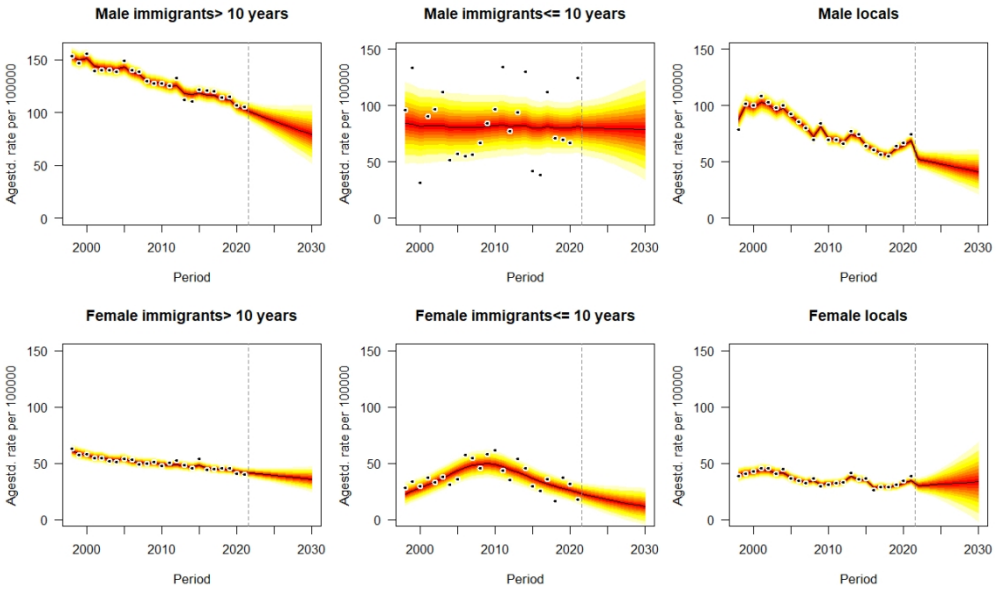

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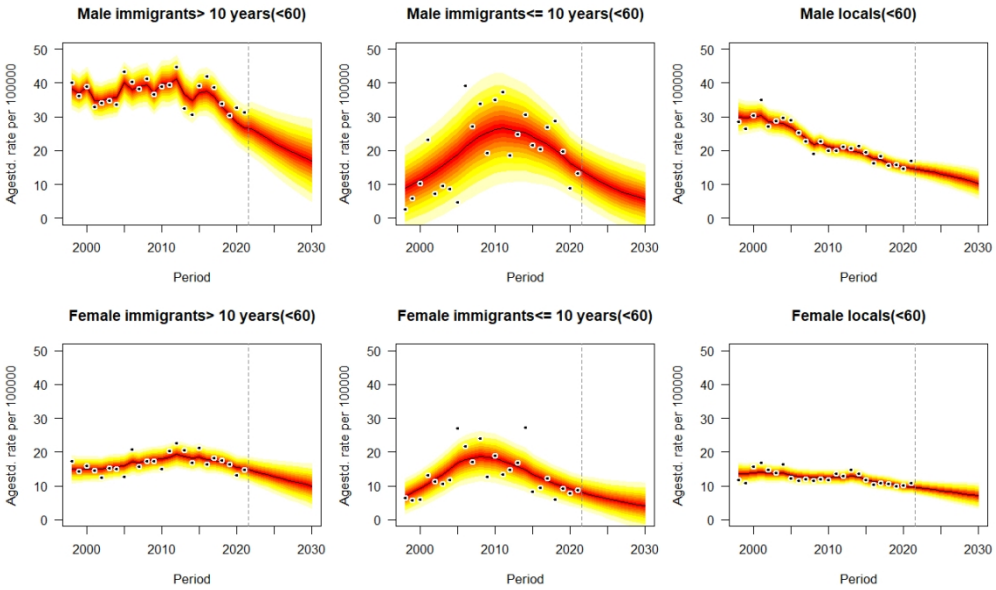

Figure 4. Projections of lung cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

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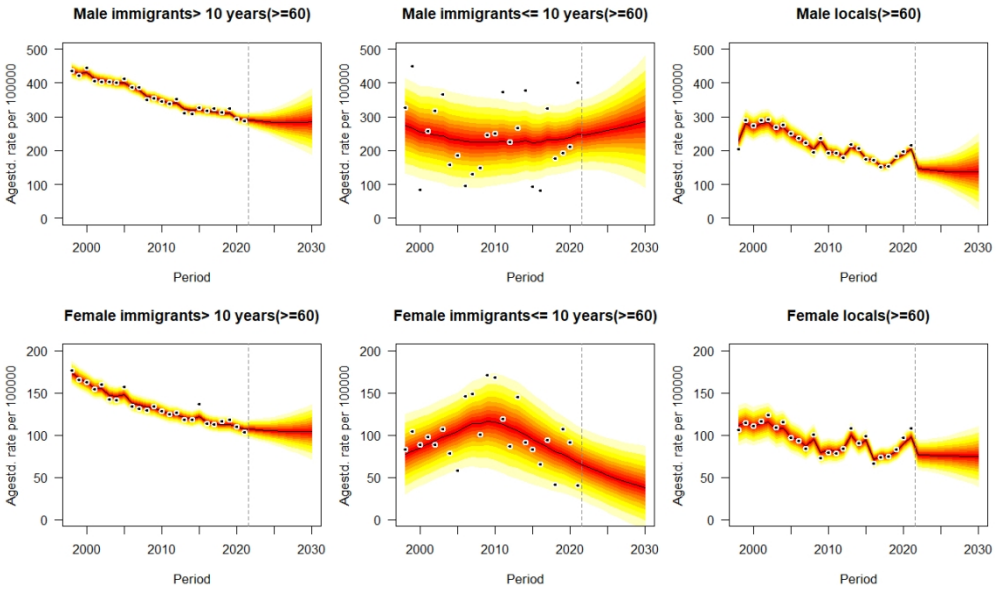

Figure 5. Projections of lung cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

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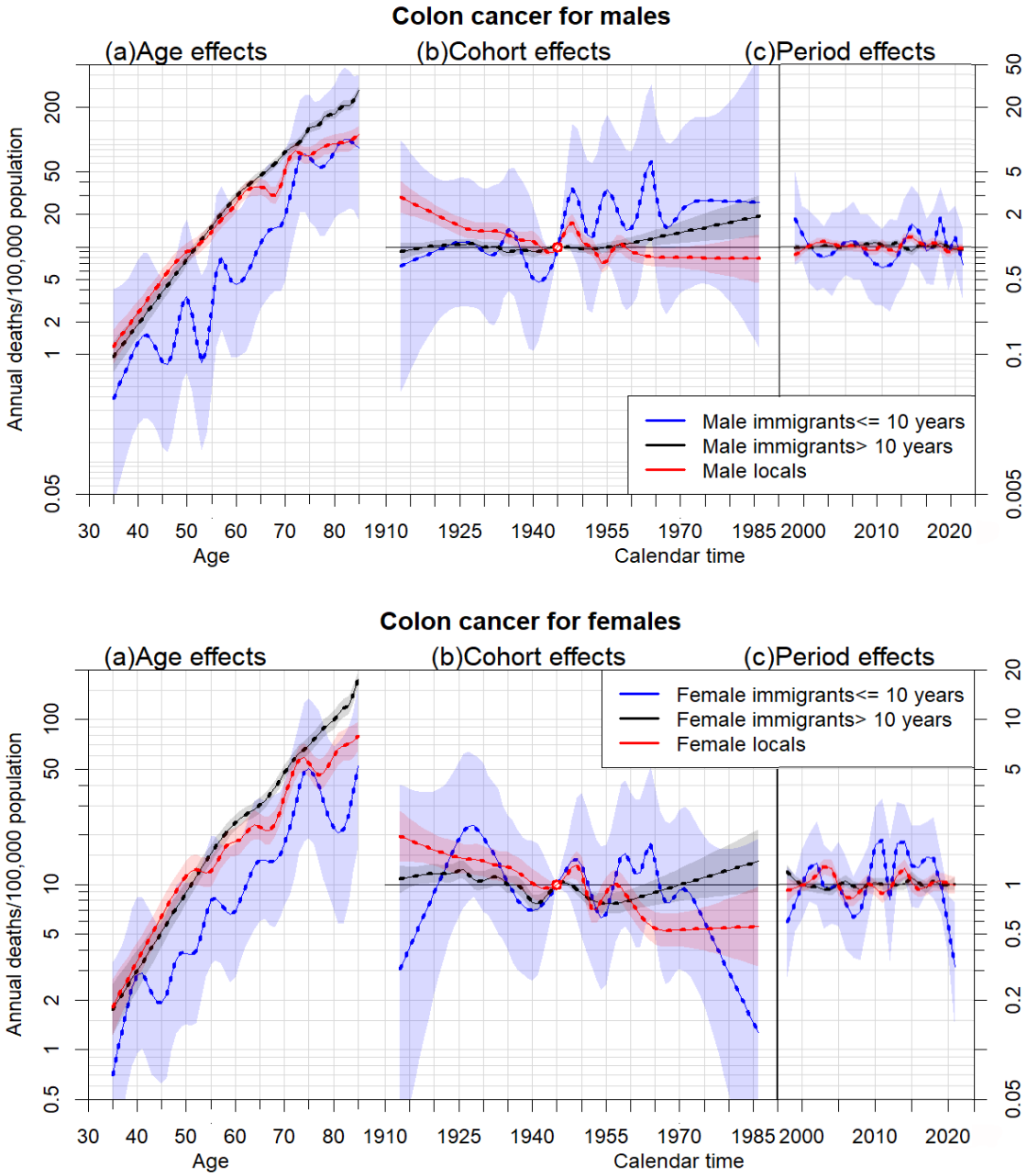
Supplementary Material for

"An age-period-cohort analysis and projection of cancer mortality in Hong Kong, 1998–2030"

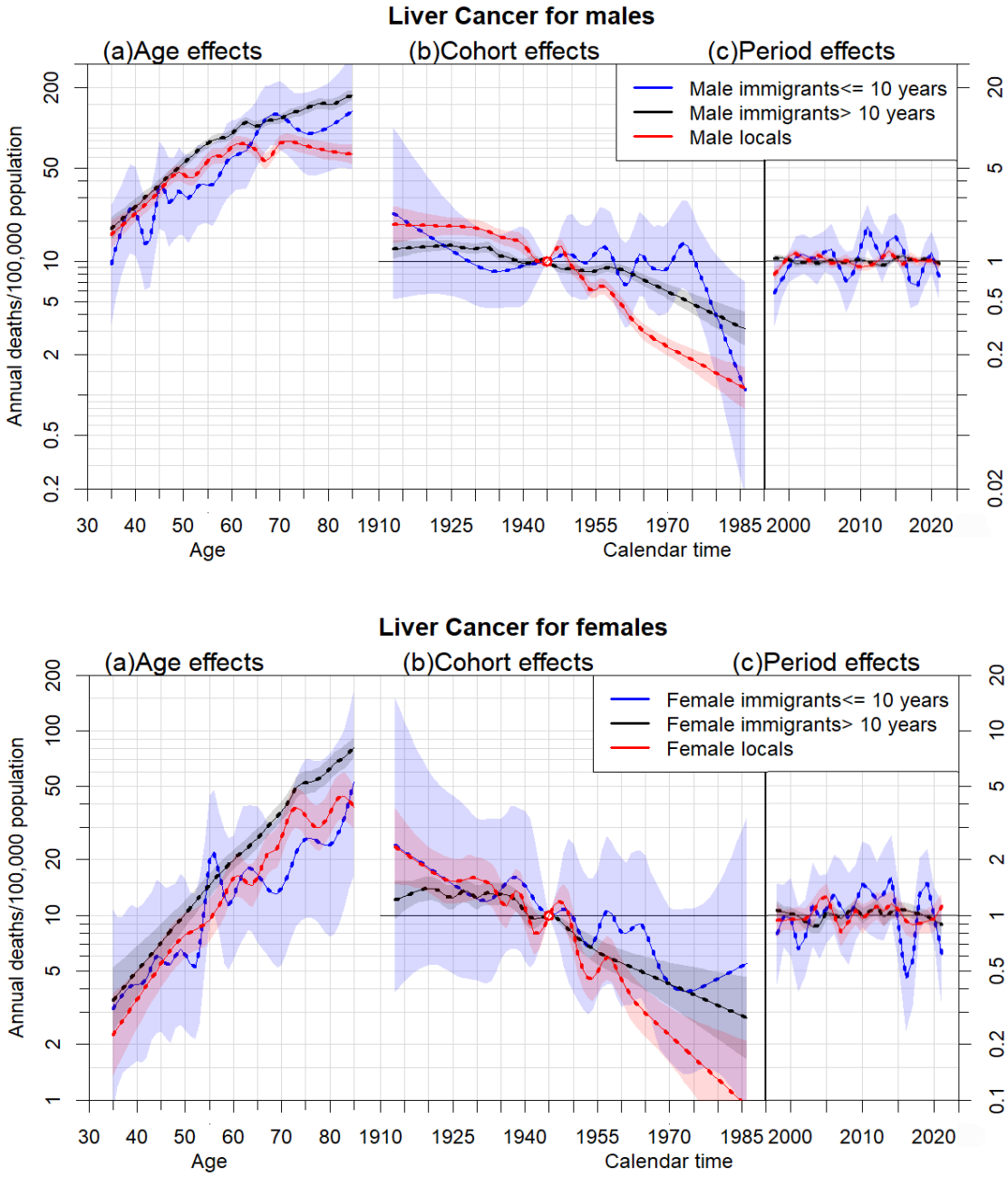
APC Figures

Projection Figures

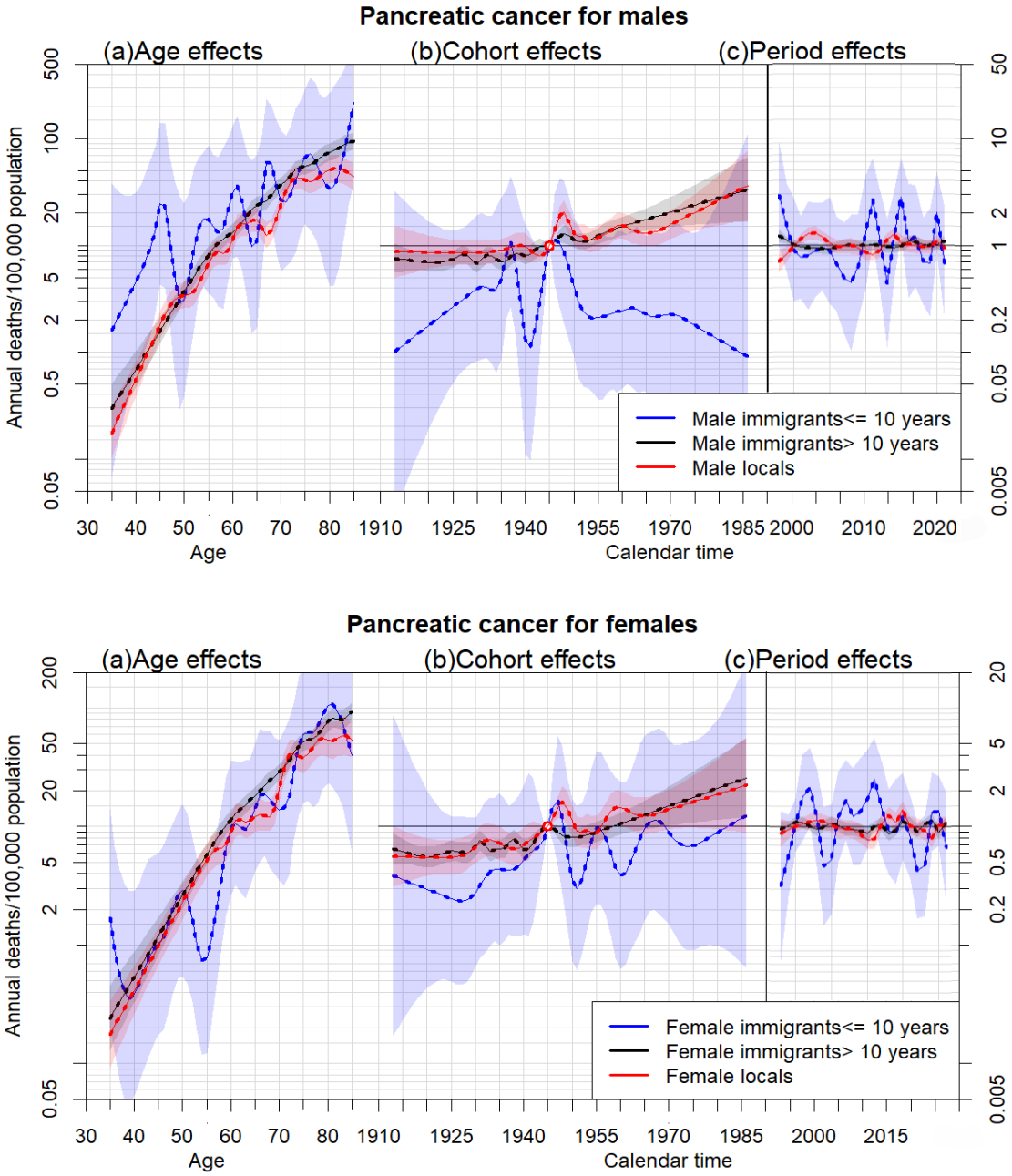
Tables



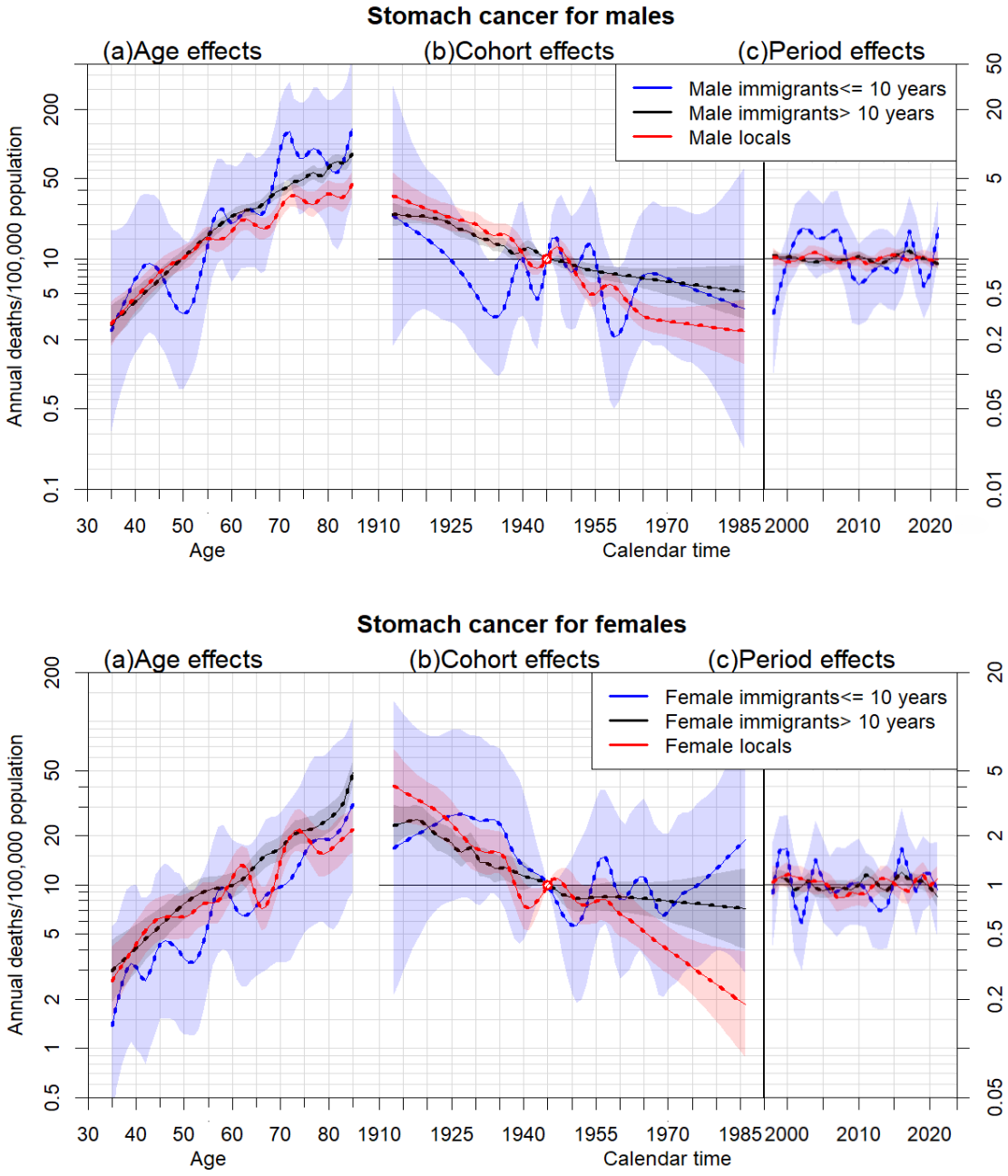
eFigure 1(a). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female colon cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



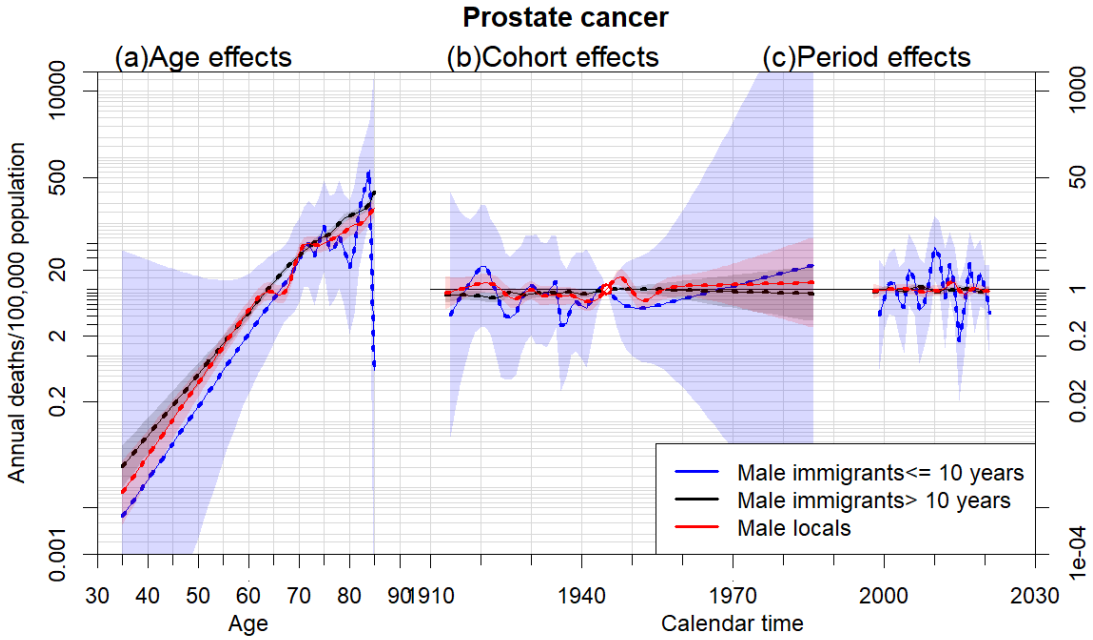
eFigure 1(b). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female liver cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



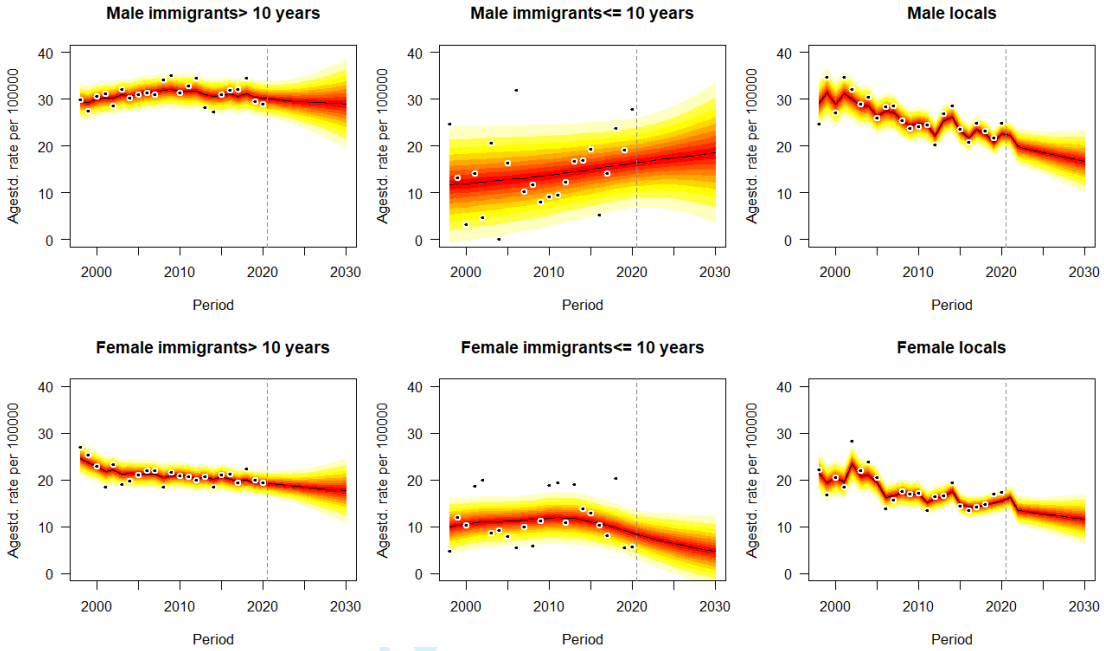
eFigure 1(c). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female pancreatic cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



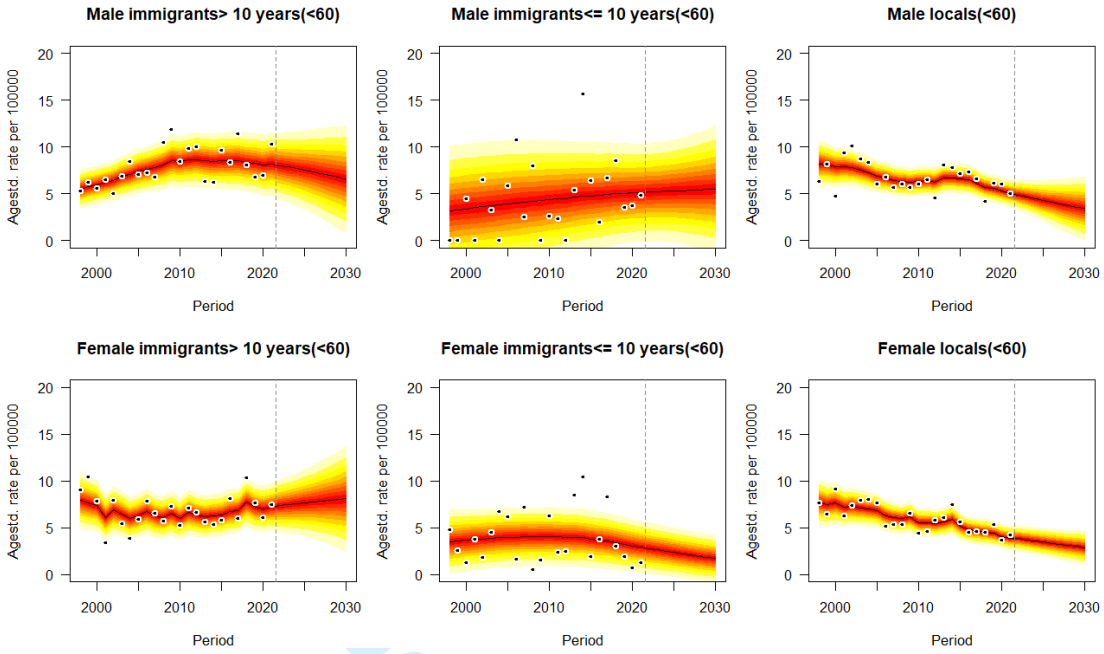
eFigure 1(d). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male and female stomach cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



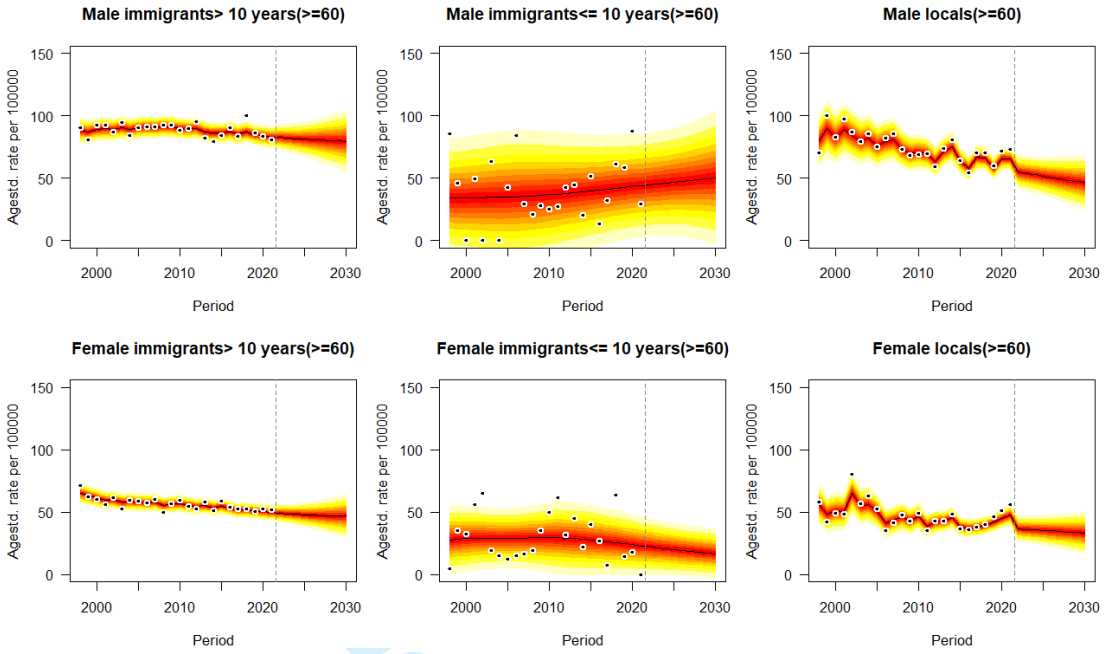
eFigure 1(e). Parameter estimates of age (a), cohort (b) and period (c) effects based on an age-period-cohort model of male prostate cancer mortality rates by immigrant groups: locals, immigrants stay in Hong Kong for more than 10 years and immigrants stay in Hong Kong for less than or equal to 10 years. Age effect was assessed by mortality (left axis). Cohort and period effects were assessed by relative risk (right axis), 95% confidence intervals are shown as shaded bands.



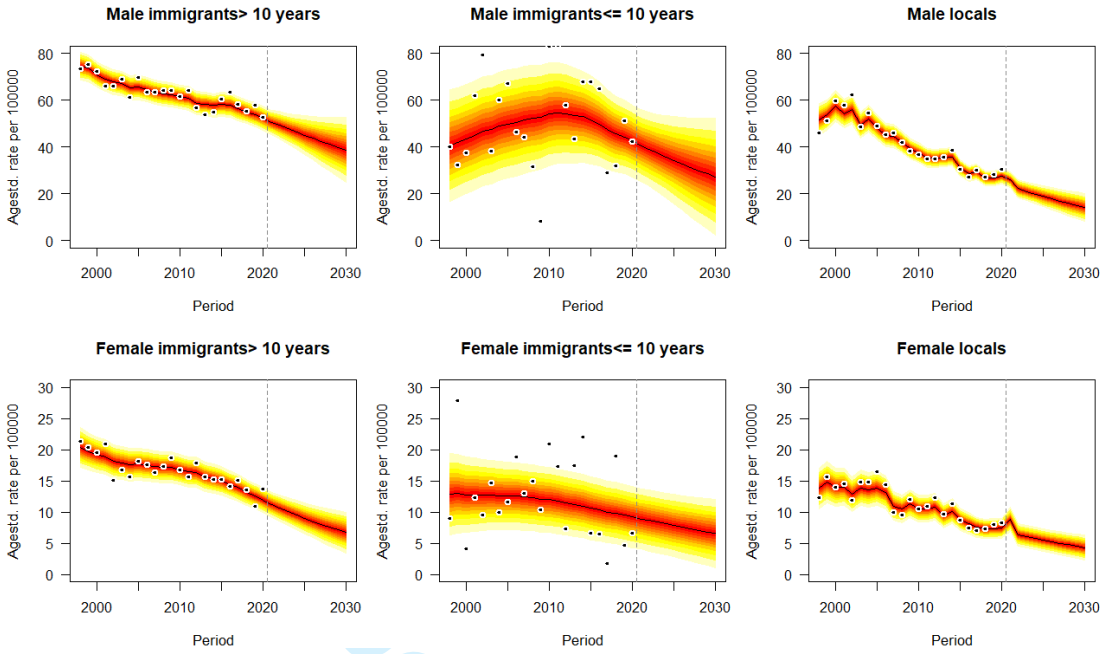
eFigure 2(a). Projections of colon cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



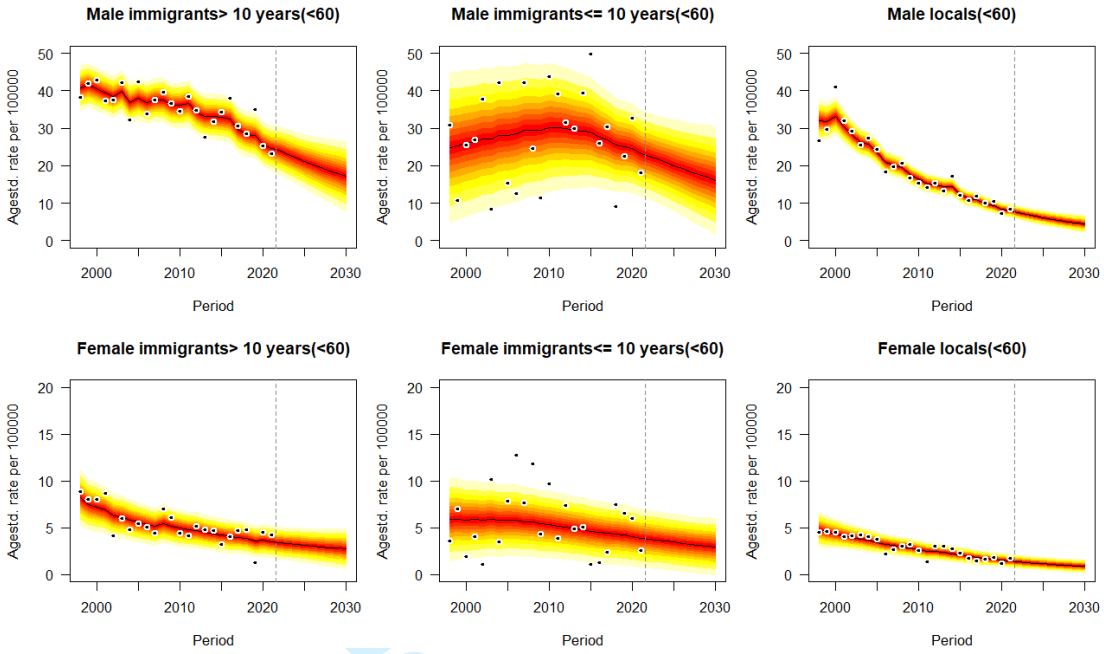
eFigure 2(b). Projections of colon cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



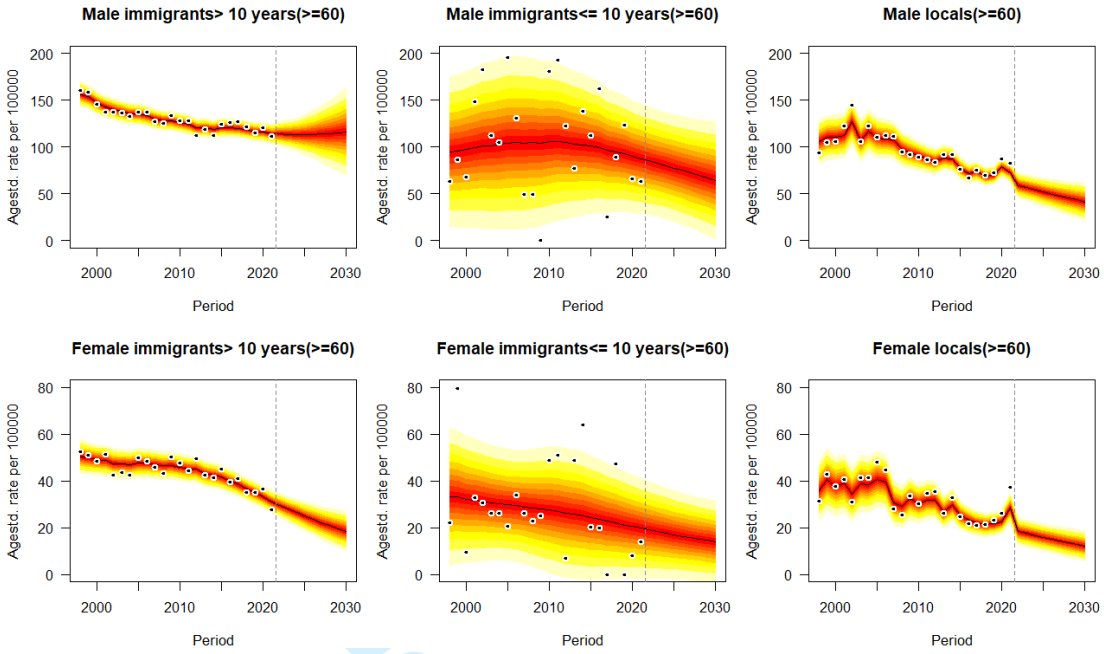
eFigure 2(c). Projections of colon cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



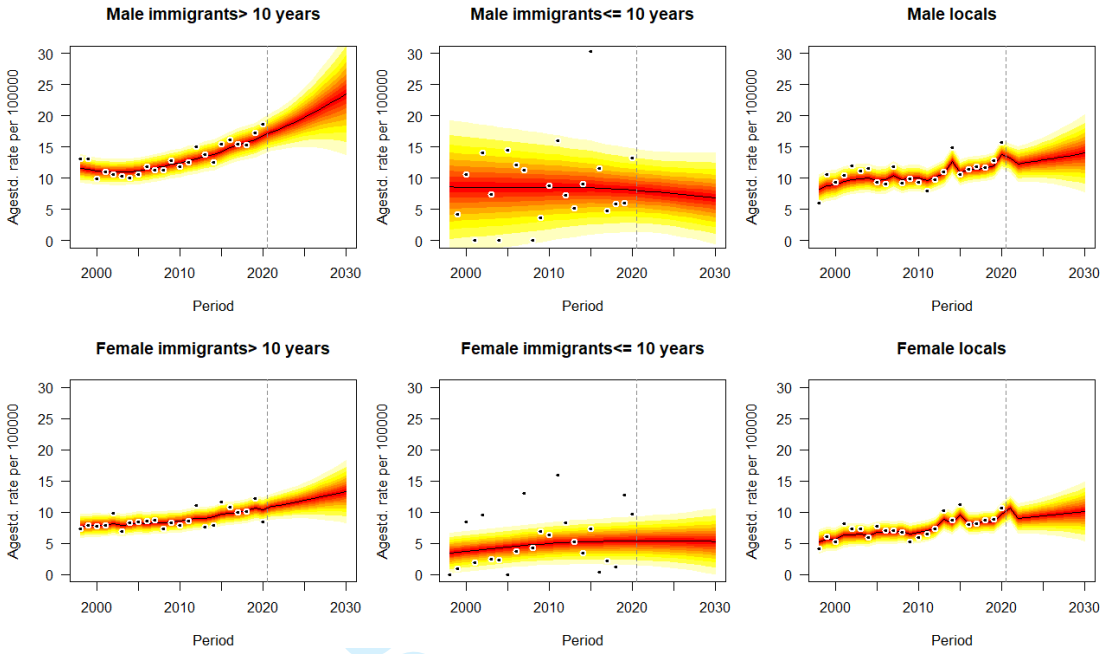
eFigure 3(a). Projections of liver cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



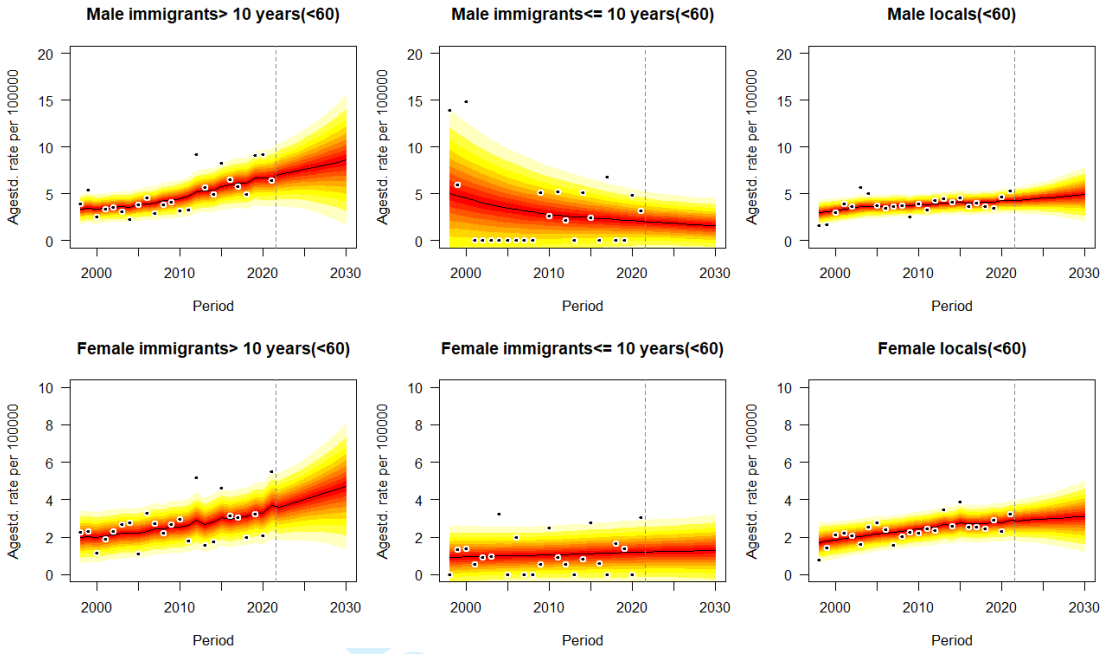
eFigure 3(b). Projections of liver cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 3(c). Projections of liver cancer mortality rates for the population older than or equal to 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 4(a). Projections of pancreatic cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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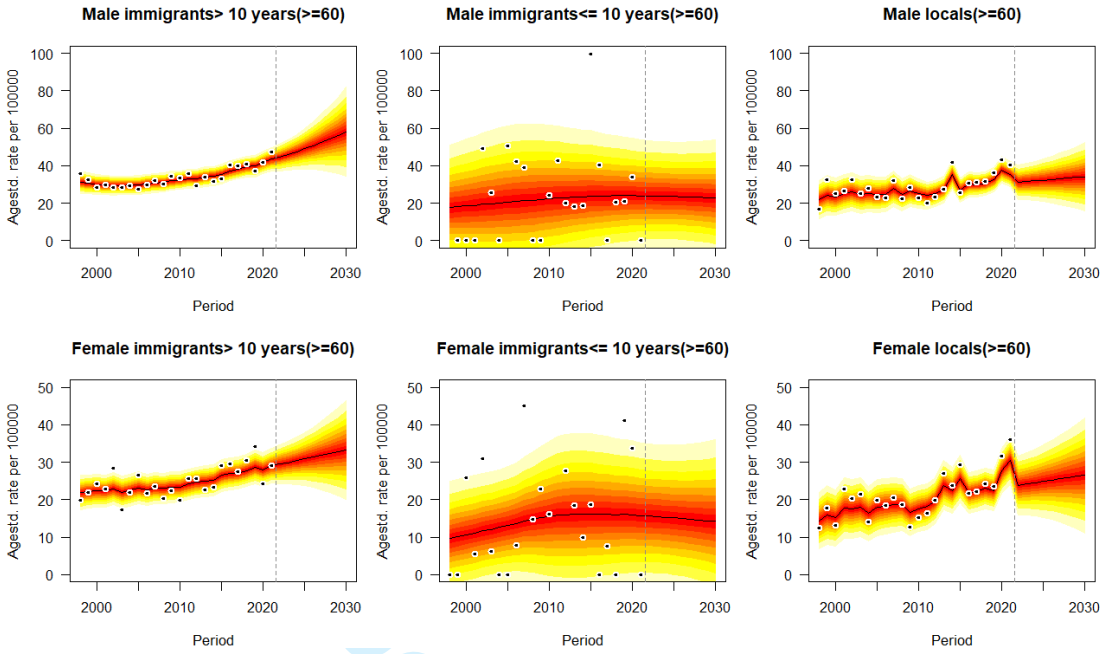

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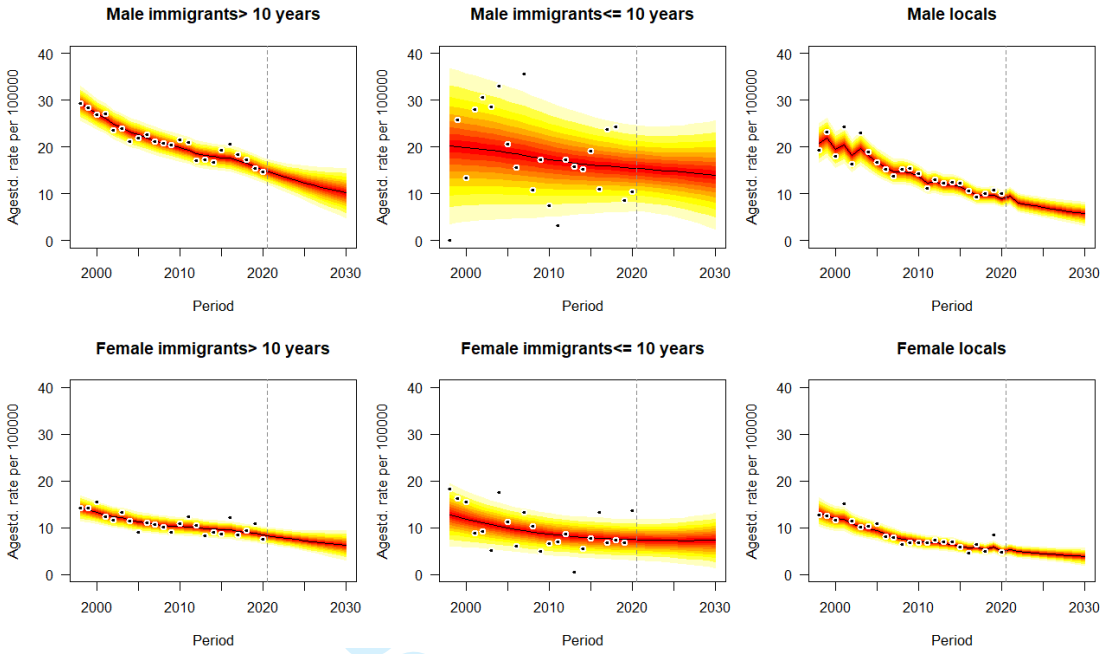
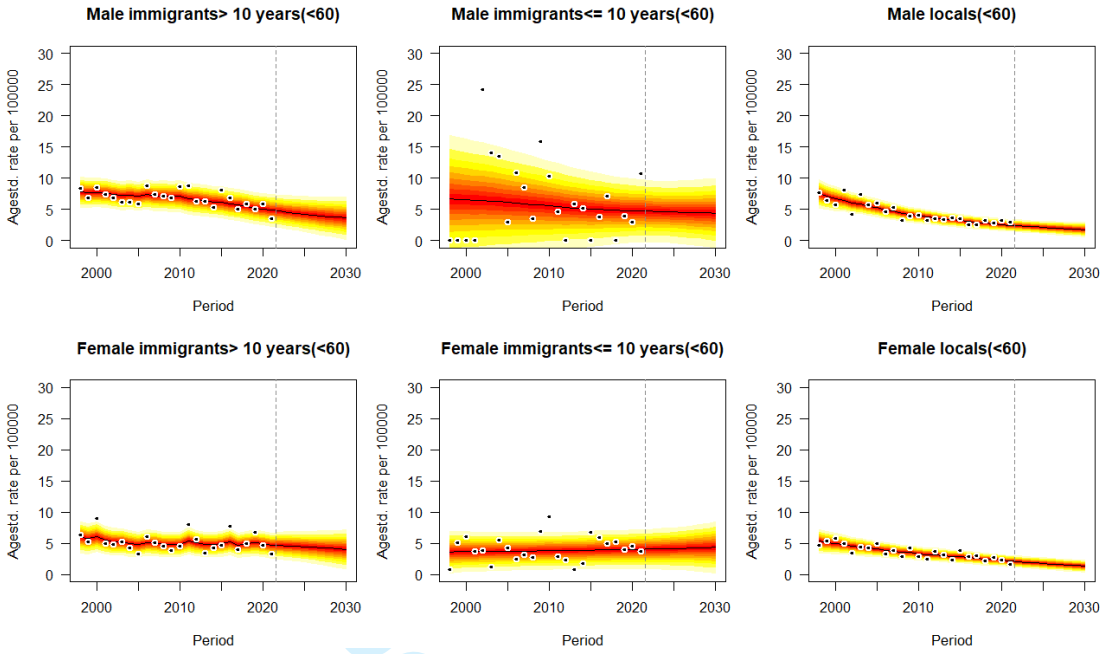
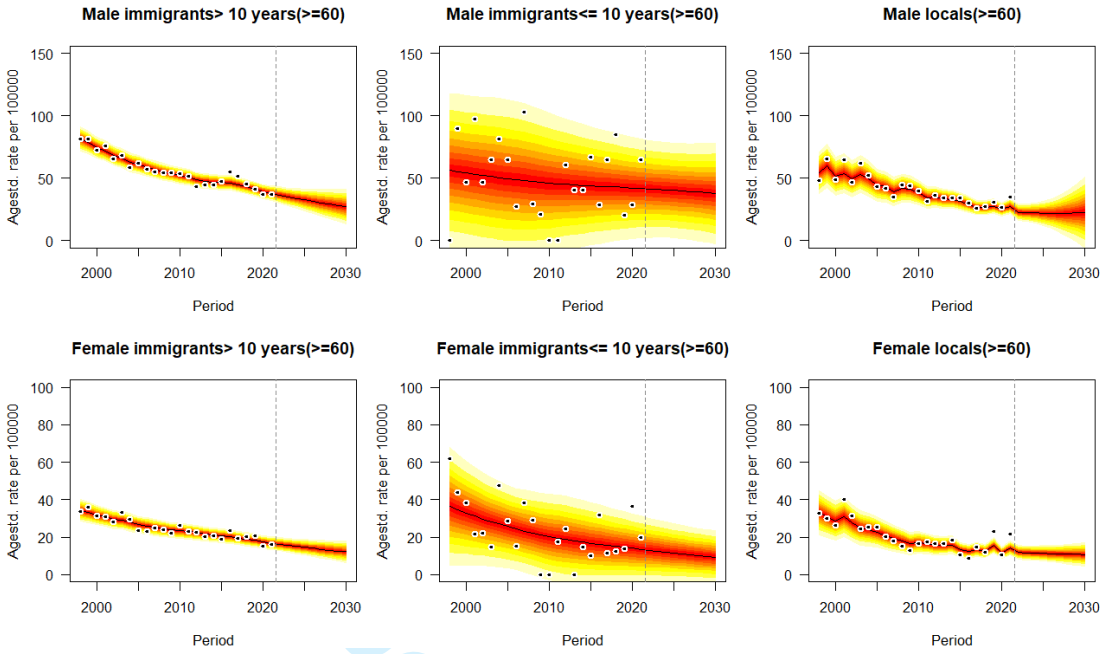


eFigure 5(a). Projections of stomach cancer mortality rates by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



eFigure 5(b). Projections of stomach cancer mortality rates for the population younger than 60 by gender and immigrant status from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.



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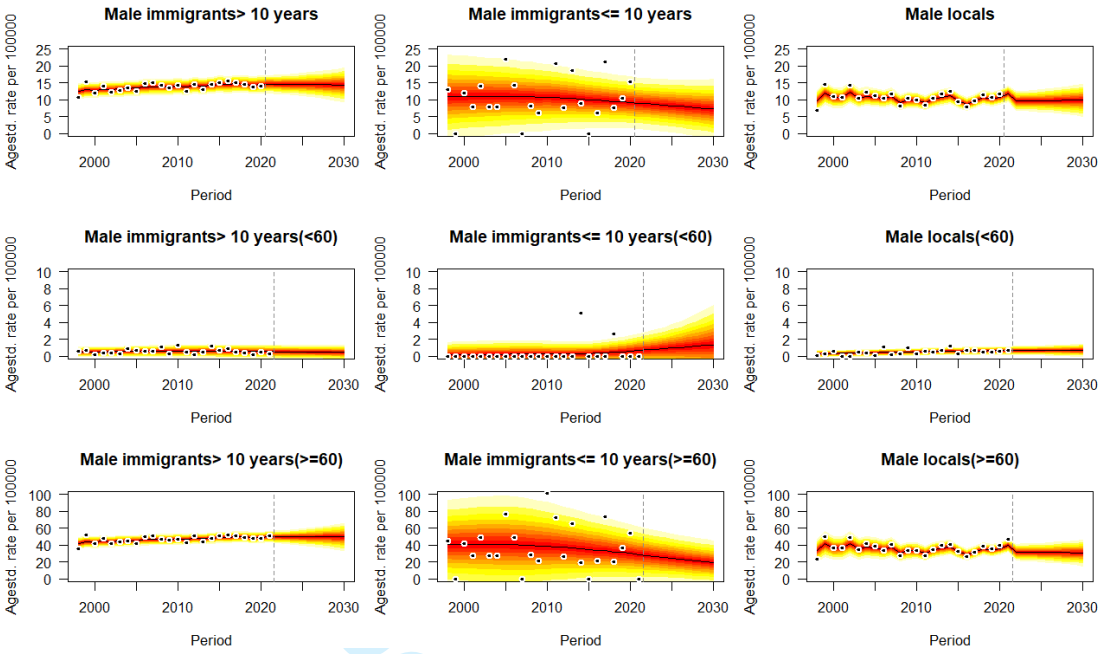

eFigure 6. Projections of prostate cancer mortality rates for males by immigrant status and age groups (less than, greater than or equal to 60 years old) from 2022 to 2030. Observations are shown as dots with the predictive distribution between the 5% and 95% quantile, whereby each lighter shade of red represents an additional 10% predictive CI. The predictive mean is shown as black solid line and the vertical dashed line indicates where prediction started.

Predictive mean of age-standardized mortality rates of lung cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	41.80 (1.27)	41.34 (1.86)	40.58 (2.27)	39.87 (2.75)	39.19 (3.28)	38.53 (3.86)	37.89 (4.46)	37.26 (5.09)	36.65 (5.74)	36.04 (6.4)
Female immigrants ≤ 10	23.92 (4.00)	22.22 (4.67)	20.56 (5.38)	19.01 (6.10)	17.57 (6.80)	16.24 (7.45)	15.00 (8.04)	13.85 (8.56)	12.79 (9.01)	11.81 (9.39)
Female locals	34.67 (1.76)	30.22 (3.54)	30.63 (4.77)	31.05 (6.38)	31.48 (8.29)	31.9 (10.47)	32.32 (12.87)	32.73 (15.48)	33.15 (18.31)	33.55 (21.33)
Male immigrants >10	102.90 (2.43)	100.18 (4.18)	97.18 (5.33)	94.34 (6.72)	91.71 (8.24)	89.15 (9.84)	86.66 (11.47)	84.19 (13.11)	81.81 (14.74)	79.55 (16.37)
Male immigrants ≤10	81.26 (9.21)	79.90 (10.41)	79.81 (11.82)	79.72 (13.42)	79.62 (15.19)	79.50 (17.09)	79.32 (19.09)	79.08 (21.18)	78.78 (23.32)	78.41 (25.53)
Male locals	60.96 (2.82)	52.27 (4.86)	50.83 (5.39)	49.56 (6.13)	48.18 (6.97)	46.64 (7.84)	45.13 (8.76)	43.83 (9.76)	42.67 (10.8)	41.43 (11.8)
Female immigrants>10(<60y)	15.51 (1.12)	14.51 (1.50)	13.90 (1.76)	13.29 (2.04)	12.71 (2.33)	12.13 (2.62)	11.57 (2.91)	11.02 (3.18)	10.49 (3.43)	9.98 (3.68)
Female immigrants ≤ 10(<60y)	8.14 (1.91)	7.79 (1.95)	7.18(2.23)	6.62(2.53)	6.10(2.81)	5.63(3.08)	5.19(3.32)	4.79 (3.53)	4.42 (3.72)	4.09 (3.88)
Female locals(<60y)	10.25 (0.77)	9.48 (0.89)	9.17(1.02)	8.87(1.16)	8.57(1.32)	8.27(1.49)	7.97(1.65)	7.68 (1.82)	7.38 (1.98)	7.09 (2.13)
Male immigrants>10(<60y)	27.81 (2.10)	26.36 (3.58)	24.96 (3.94)	23.64 (4.35)	22.38 (4.79)	21.17 (5.23)	20.03 (5.67)	18.96 (6.10)	17.96 (6.51)	17.03 (6.90)
Male immigrants ≤ 10(<60y)	15.01 (2.98)	13.38 (3.71)	12.02 (4.17)	10.79 (4.59)	9.68 (4.95)	8.69 (5.24)	7.79 (5.46)	6.98 (5.61)	6.25 (5.69)	5.59 (5.72)
Male locals(<60y)	15.19 (0.78)	14.45 (1.15)	14.03 (1.29)	13.61 (1.46)	13.14 (1.64)	12.65 (1.82)	12.13 (2.01)	11.55 (2.17)	10.93 (2.31)	10.26 (2.43)
Female immigrants >10(≥ 60y)	108.85 (4.80)	107.21 (5.17)	106.26 (6.24)	105.52 (7.54)	104.94 (9.04)	104.51 (10.72)	104.21 (12.57)	104.07 (14.61)	104.06 (16.78)	104.16 (19.14)
Female immigrants ≤ 10(≥60y)	66.16 (13.25)	63.84 (15.72)	59.88 (17.50)	56.14 (19.31)	52.60 (21.03)	49.27 (22.66)	46.14 (24.16)	43.20 (25.52)	40.44 (26.74)	37.85 (27.81)
Female locals(≥60y)	77.33 (9.40)	76.53 (10.11)	76.22 (10.85)	75.94 (11.79)	75.69 (12.94)	75.49 (14.28)	75.32 (15.80)	75.19 (17.48)	75.10 (19.33)	75.03 (21.32)
Male immigrants>10(≥60y)	293.56 (9.13)	289.8 (11.7)	286.6 (15.19)	284.28 (19.51)	282.78 (24.49)	281.99 (30.07)	281.88 (36.31)	282.31 (43.15)	283.37 (50.66)	285.03 (58.86)
Male immigrants ≤ 10(≥60y)	244.88 (30.29)	247.01 (36.85)	251.24 (42.94)	255.62 (50.06)	260.14 (58.14)	264.82 (67.14)	269.61 (77.01)	274.52 (87.75)	279.55 (99.34)	284.69 (111.81)
Male locals(≥60y)	150.75 (16.22)	146.29 (18.46)	143.54 (20.58)	141.84 (23.97)	140.07 (28.24)	138.14 (33.39)	136.65 (39.82)	136.49 (47.87)	137.24 (57.47)	138.26 (68.52)

eTable 1. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of lung cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of colon cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	20.03 (0.95)	18.95 (1.13)	18.77 (1.37)	18.59 (1.66)	18.42 (1.98)	18.27 (2.33)	18.12 (2.71)	17.98 (3.11)	17.85 (3.53)	17.73 (3.96)
Female immigrants ≤ 10	8.11 (2.19)	7.70 (2.51)	7.25 (2.81)	6.82 (3.11)	6.42 (3.37)	6.03 (3.61)	5.67 (3.83)	5.33 (4.01)	5.01 (4.17)	4.71 (4.31)
Female locals	13.77 (1.30)	13.47 (1.61)	13.24 (1.72)	13.01 (1.87)	12.77 (2.04)	12.53 (2.24)	12.29 (2.46)	12.06 (2.68)	11.82 (2.92)	11.59 (3.16)
Male immigrants >10	31.22 (1.28)	29.82 (1.46)	29.66 (1.79)	29.52 (2.19)	29.41 (2.63)	29.30 (3.11)	29.21 (3.64)	29.14 (4.19)	29.06 (4.78)	28.98 (5.39)
Male immigrants ≤10	15.47 (2.14)	16.77 (3.77)	17.02 (4.18)	17.23 (4.64)	17.45 (5.14)	17.67 (5.69)	17.88 (6.27)	18.09 (6.91)	18.31 (7.56)	18.50 (8.26)
Male locals	21.28 (1.38)	19.81 (2.07)	19.39 (2.22)	18.97 (2.42)	18.57 (2.61)	18.18 (2.85)	17.81 (3.12)	17.43 (3.40)	17.06 (3.71)	16.71 (4.03)
Female immigrants >10(<60y)	7.09 (0.99)	7.36 (1.12)	7.46 (1.28)	7.56 (1.46)	7.65 (1.68)	7.74 (1.92)	7.83 (2.19)	7.92 (2.48)	8.01 (2.79)	8.09 (3.13)
Female immigrants ≤ 10(<60y)	3.11 (0.67)	2.82 (0.86)	2.65 (0.91)	2.51 (0.97)	2.36 (1.02)	2.22 (1.07)	2.08 (1.11)	1.95 (1.14)	1.83 (1.18)	1.72 (1.22)
Female locals(<60y)	4.10 (0.41)	3.87 (0.50)	3.73 (0.54)	3.61 (0.59)	3.47 (0.65)	3.34 (0.70)	3.22 (0.76)	3.11 (0.82)	2.99 (0.88)	2.88 (0.94)
Male immigrants >10(<60y)	8.29 (0.91)	7.98 (1.17)	7.85 (1.38)	7.71 (1.60)	7.54 (1.83)	7.36 (2.08)	7.17(2.32)	6.97(2.57)	6.76(2.81)	6.55(3.05)
Male immigrants ≤ 10(<60y)	5.03 (1.44)	5.18 (1.58)	5.22 (1.75)	5.26 (1.93)	5.30 (2.14)	5.34 (2.36)	5.38(2.59)	5.43(2.84)	5.47(3.11)	5.51(3.38)
Male locals(<60y)	5.14 (0.43)	4.88 (0.63)	4.66 (0.79)	4.46 (0.96)	4.26 (1.13)	4.08 (1.31)	3.91(1.48)	3.73(1.65)	3.57(1.82)	3.42(1.97)
Female immigrants >10(≥60y)	52.16 (2.59)	49.21 (2.99)	48.70 (3.56)	48.26 (4.26)	47.87 (5.05)	47.54 (5.94)	47.26 (6.90)	47.05 (7.94)	46.91 (9.06)	46.81 (10.26)
Female immigrants ≤ 10(≥60y)	24.01 (5.83)	22.44 (6.56)	21.69 (6.96)	20.95 (7.38)	20.23 (7.80)	19.52 (8.23)	18.84 (8.66)	18.17 (9.08)	17.51 (9.49)	16.86 (9.90)
Female locals(≥60y)	37.42 (5.31)	36.69 (5.74)	36.29 (6.06)	35.87 (6.46)	35.46 (6.95)	35.04 (7.5)	34.61 (8.12)	34.19 (8.79)	33.77 (9.51)	33.34 (10.27)
Male immigrants >10(≥60y)	84.17 (3.55)	82.72 (4.09)	82.16 (4.95)	81.64 (5.97)	81.19 (7.12)	80.81 (8.39)	80.47 (9.77)	80.15 (11.24)	79.85 (12.81)	79.56 (14.45)
Male immigrants ≤ 10(≥60y)	43.25 (11.07)	44.93 (13.09)	45.62 (14.52)	46.30 (16.09)	46.96 (17.80)	47.61 (19.64)	48.25 (21.62)	48.88 (23.73)	49.51 (25.97)	50.13 (28.34)
Male locals(≥60y)	55.79 (6.86)	54.89 (7.65)	53.75 (8.03)	52.63 (8.52)	51.54 (9.12)	50.47 (9.8)	49.43 (10.55)	48.42 (11.37)	47.42 (12.25)	46.44 (13.16)

eTable 2. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of colon cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of liver cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	11.34 (0.66)	10.68 (0.71)	10.09 (0.85)	9.54 (1.01)	9.01 (1.16)	8.50 (1.31)	8.02(1.45)	7.57(1.59)	7.14(1.72)	6.74(1.83)
Female immigrants ≤10	9.15 (1.55)	8.66 (1.82)	8.38 (1.95)	8.11 (2.08)	7.84 (2.22)	7.58 (2.36)	7.32(2.49)	7.07(2.63)	6.82(2.76)	6.58(2.88)
Female locals	6.72 (0.69)	6.36 (0.88)	6.08 (0.90)	5.81 (0.93)	5.53 (0.97)	5.26 (1.01)	5.01(1.06)	4.77(1.11)	4.53(1.15)	4.3(1.21)
Male immigrants >10	52.17 (1.78)	49.22 (2.36)	47.76 (2.93)	46.35 (3.59)	45.01 (4.31)	43.67 (5.05)	42.37 (5.81)	41.1(6.56)	39.89 (7.33)	38.71 (8.08)
Male immigrants ≤10	42.33 (5.87)	39.03 (6.49)	37.39 (7.47)	35.81 (8.51)	34.26 (9.58)	32.76 (10.63)	31.31 (11.65)	29.91 (12.62)	28.56 (13.54)	27.25 (14.40)
Male locals	24.22 (1.77)	22.16 (2.09)	21.02 (2.22)	19.91 (2.39)	18.85 (2.58)	17.83 (2.79)	16.85 (3.03)	15.92 (3.21)	15.03 (3.40)	14.18 (3.59)
Female immigrants >10(<60y)	3.62 (0.45)	3.39 (0.52)	3.29 (0.57)	3.20 (0.63)	3.12 (0.69)	3.04 (0.75)	2.96(0.82)	2.89(0.89)	2.82(0.96)	2.75(1.03)
Female immigrants ≤ 10(<60y)	4.10 (0.79)	3.81 (0.91)	3.69 (0.96)	3.57 (1.02)	3.46 (1.08)	3.36 (1.15)	3.25(1.22)	3.15(1.29)	3.06(1.36)	2.97(1.43)
Female locals(<60y)	1.50 (0.13)	1.37 (0.2)	1.29 (0.21)	1.22 (0.23)	1.16 (0.24)	1.10 (0.26)	1.04(0.27)	0.99(0.29)	0.94(0.30)	0.89(0.31)
Male immigrants >10(<60y)	26.32 (2.11)	24.04 (2.35)	23.02 (2.63)	22.05 (2.94)	21.13 (3.27)	20.25 (3.61)	19.41 (3.95)	18.62 (4.30)	17.86 (4.64)	17.14 (4.98)
Male immigrants ≤ 10(<60y)	25.52 (2.99)	22.56 (3.96)	21.71 (4.44)	20.87 (4.94)	20.04 (5.45)	19.22 (5.95)	18.42 (6.45)	17.63 (6.91)	16.86 (7.36)	16.11 (7.78)
Male locals(<60y)	8.25 (0.69)	7.47 (0.74)	6.97 (0.79)	6.52 (0.86)	6.11 (0.93)	5.73 (1.01)	5.38(1.08)	5.04(1.15)	4.73(1.21)	4.44(1.27)
Female immigrants >10(≥ 60y)	33.67 (1.88)	29.63 (2.01)	27.99 (2.36)	26.42 (2.75)	24.92 (3.14)	23.49 (3.52)	22.13 (3.88)	20.85 (4.23)	19.64 (4.55)	18.50 (4.85)
Female immigrants ≤10(≥ 60y)	21.72 (5.11)	19.08 (5.81)	18.38 (6.14)	17.71 (6.48)	17.03 (6.83)	16.39 (7.16)	15.76 (7.49)	15.16 (7.80)	14.57 (8.11)	14.01 (8.39)
Female locals(≥60y)	20.63 (3.03)	18.41 (3.23)	17.55 (3.26)	16.72 (3.32)	15.91 (3.40)	15.11 (3.49)	14.34 (3.59)	13.59 (3.69)	12.87 (3.81)	12.17 (3.93)
Male immigrants >10(≥ 60y)	115.39 (4.54)	113.96 (5.95)	113.43 (7.65)	113.17 (9.70)	113.16 (12.04)	113.37 (14.66)	113.79 (17.56)	114.39 (20.73)	115.19 (24.18)	116.17 (27.91)
Male immigrants ≤10(≥ 60y)	88.61 (15.58)	85.14 (18.85)	82.59 (20.6)	80.02 (22.44)	77.42 (24.34)	74.83 (26.24)	72.23 (28.12)	69.64 (29.94)	67.07 (31.70)	64.52 (33.38)
Male locals(≥60y)	62.88 (5.97)	58.95 (7.91)	56.51 (8.20)	54.14 (8.61)	51.84 (9.12)	49.61 (9.70)	47.46 (10.33)	45.38 (11.01)	43.38 (11.68)	41.45 (12.36)

eTable 3. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of liver cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of pancreatic cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	10.89 (0.62)	11.11 (0.75)	11.36 (0.91)	11.61 (1.09)	11.87 (1.31)	12.14 (1.56)	12.42 (1.84)	12.71 (2.15)	13.01 (2.48)	13.3(2.85)
Female immigrants ≤ 10	5.51 (1.44)	5.44 (1.56)	5.44 (1.69)	5.43(1.84)	5.42(1.99)	5.41(2.15)	5.39(2.32)	5.36(2.49)	5.34(2.66)	5.31(2.84)
Female locals	8.79 (1.10)	9.01 (1.22)	9.15 (1.34)	9.29(1.48)	9.43(1.64)	9.57(1.83)	9.71(2.05)	9.85(2.28)	9.99(2.54)	10.14 (2.83)
Male immigrants >10	16.30 (0.98)	17.87 (1.19)	18.48 (1.49)	19.11 (1.87)	19.78 (2.32)	20.47 (2.83)	21.18 (3.42)	21.92 (4.07)	22.69 (4.81)	23.49 (5.61)
Male immigrants ≤10	8.10 (2.02)	7.87 (2.37)	7.76 (2.53)	7.64(2.70)	7.51(2.87)	7.38(3.05)	7.24(3.23)	7.09(3.41)	6.95(3.58)	6.81(3.75)
Male locals	11.97 (1.26)	12.29 (1.49)	12.49 (1.64)	12.69 (1.83)	12.91 (2.06)	13.11 (2.33)	13.33 (2.63)	13.55 (2.97)	13.78 (3.34)	14.02 (3.74)
Female immigrants >10(<60y)	3.47 (0.33)	3.62 (0.57)	3.74 (0.66)	3.87(0.77)	4.01(0.89)	4.14(1.02)	4.28(1.18)	4.42(1.34)	4.57(1.53)	4.72(1.73)
Female immigrants ≤ 10(<60y)	1.12 (0.33)	1.21 (0.48)	1.22 (0.52)	1.23(0.56)	1.24(0.61)	1.25(0.66)	1.26(0.71)	1.26(0.77)	1.27(0.83)	1.28(0.89)
Female locals(<60y)	2.76 (0.27)	2.88 (0.36)	2.91 (0.41)	2.93(0.48)	2.96(0.55)	2.99(0.63)	3.02(0.71)	3.04(0.81)	3.07(0.90)	3.10(1.01)
Male immigrants >10(<60y)	6.88 (0.98)	7.05 (1.11)	7.24 (1.32)	7.43(1.56)	7.62(1.84)	7.82(2.16)	8.01(2.50)	8.21(2.88)	8.40(3.30)	8.61(3.75)
Male immigrants ≤ 10(<60y)	2.20 (0.71)	2.01 (0.85)	1.95 (0.91)	1.9(0.94)	1.84(0.99)	1.79(1.04)	1.74(1.09)	1.69(1.14)	1.64(1.19)	1.60(1.24)
Male locals(<60y)	4.16 (0.35)	4.33 (0.48)	4.41 (0.57)	4.46(0.68)	4.53(0.81)	4.61(0.94)	4.69(1.09)	4.77(1.26)	4.85(1.44)	4.93(1.63)
Female immigrants >10(≥60y)	28.58 (1.83)	29.45 (2.11)	29.91 (2.54)	30.38 (3.06)	30.85 (3.66)	31.33 (4.33)	31.81 (5.08)	32.29 (5.91)	32.78 (6.79)	33.27 (7.74)
Female immigrants ≤ 10(≥60y)	16.79 (5.29)	15.65 (6.08)	15.49 (6.71)	15.33 (7.36)	15.16 (8.03)	14.97 (8.73)	14.79 (9.43)	14.59 (10.14)	14.39 (10.86)	14.19 (11.58)
Female locals(≥60y)	22.80 (4.23)	23.85 (4.46)	24.21 (4.81)	24.56 (5.23)	24.91 (5.73)	25.25 (6.30)	25.58 (6.95)	25.90 (7.67)	26.22 (8.47)	26.54 (9.34)
Male immigrants >10(≥60y)	42.70 (2.55)	44.36 (3.02)	45.85 (3.76)	47.41 (4.69)	49.04 (5.78)	50.73 (7.05)	52.48 (8.50)	54.28 (10.13)	56.16 (11.95)	58.11 (13.98)
Male immigrants ≤ 10(≥60y)	24.68 (8.21)	23.96 (9.01)	23.87 (9.74)	23.75 (10.52)	23.61 (11.33)	23.45 (12.17)	23.28 (13.04)	23.09 (13.93)	22.89 (14.83)	22.68 (15.75)
Male locals(≥60y)	30.10 (4.68)	31.17 (5.22)	31.55 (5.63)	31.93 (6.14)	32.30 (6.75)	32.66 (7.45)	33.01 (8.23)	33.35 (9.11)	33.69 (10.08)	34.03 (11.12)

eTable 4. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of pancreatic cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of stomach cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Female immigrants >10	8.20 (0.55)	7.95 (0.62)	7.71 (0.74)	7.47 (0.87)	7.25 (1.01)	7.03 (1.15)	6.83 (1.29)	6.62 (1.43)	6.43 (1.57)	6.24 (1.71)
Female immigrants ≤ 10	7.51 (1.44)	7.36 (1.56)	7.33 (1.69)	7.30 (1.85)	7.28 (2.01)	7.27 (2.20)	7.27 (2.40)	7.28 (2.61)	7.31 (2.84)	7.33 (3.09)
Female locals	5.26 (0.40)	4.91 (0.52)	4.75 (0.57)	4.61 (0.63)	4.47 (0.71)	4.34 (0.77)	4.21 (0.84)	4.08 (0.91)	3.95 (0.99)	3.83 (1.06)
Male immigrants >10	15.22 (0.64)	13.89 (0.97)	13.34(1.21)	12.81 (1.46)	12.31 (1.73)	11.83 (1.99)	11.38 (2.26)	10.95 (2.51)	10.54 (2.76)	10.15 (3.01)
Male immigrants ≤10	15.83 (3.04)	15.21 (3.38)	15.07 (3.67)	14.93 (3.98)	14.79 (4.31)	14.64 (4.65)	14.51 (5.02)	14.35 (5.39)	14.19 (5.78)	14.03 (6.17)
Male locals	8.14 (0.89)	8.07 (0.99)	7.73 (1.03)	7.41(1.07)	7.10 (1.13)	6.81 (1.19)	6.51 (1.26)	6.23 (1.33)	5.97 (1.39)	5.71 (1.46)
Female immigrants >10(<60y)	4.81 (0.56)	4.69 (0.79)	4.62 (0.87)	4.55 (0.96)	4.47 (1.07)	4.39 (1.17)	4.31 (1.29)	4.22 (1.41)	4.13 (1.52)	4.03 (1.64)
Female immigrants ≤ 10(<60y)	3.89 (0.80)	4.08 (0.93)	4.10 (1.03)	4.13 (1.14)	4.17 (1.27)	4.21 (1.41)	4.24 (1.55)	4.28 (1.70)	4.32 (1.87)	4.36 (2.05)
Female locals(<60y)	2.28 (0.21)	2.08 (0.27)	1.98 (0.29)	1.88 (0.32)	1.79 (0.35)	1.71 (0.37)	1.61 (0.41)	1.53 (0.43)	1.44 (0.45)	1.37 (0.47)
Male immigrants >10(<60y)	4.94 (0.57)	4.71 (0.79)	4.55 (0.89)	4.41 (0.99)	4.25 (1.10)	4.12 (1.21)	3.98 (1.32)	3.86 (1.43)	3.74 (1.54)	3.63 (1.65)
Male immigrants ≤ 10(<60y)	4.81 (1.31)	4.70 (1.42)	4.66 (1.55)	4.63 (1.69)	4.59 (1.83)	4.55 (1.99)	4.52 (2.15)	4.48 (2.32)	4.44 (2.50)	4.41 (2.68)
Male locals(<60y)	2.48 (0.21)	2.37 (0.29)	2.28 (0.32)	2.21 (0.35)	2.12 (0.38)	2.04 (0.42)	1.97 (0.45)	1.91 (0.49)	1.83 (0.52)	1.77(0.55)
Female immigrants >10(≥60y)	17.80 (1.04)	16.23 (1.26)	15.65 (1.47)	15.08 (1.70)	14.55 (1.94)	14.03 (2.18)	13.54 (2.43)	13.07 (2.68)	12.62 (2.92)	12.19 (3.16)
Female immigrants ≤ 10(≥60y)	14.72 (4.29)	13.01 (4.83)	12.52 (5.11)	12.03 (5.37)	11.55 (5.63)	11.08 (5.88)	10.63 (6.12)	10.19 (6.35)	9.76(6.56)	9.34 (6.75)
Female locals(≥60y)	12.20 (1.66)	11.86 (1.84)	11.67 (1.98)	11.49 (2.15)	11.33 (2.35)	11.18 (2.58)	11.04 (2.84)	10.91 (3.11)	10.79(3.4)	10.68 (3.71)
Male immigrants >10(≥60y)	37.23 (2.29)	36.59 (2.56)	35.17(3.18)	33.82 (3.86)	32.55 (4.57)	31.34 (5.28)	30.19 (6.01)	29.08 (6.70)	28.02 (7.40)	27.01 (8.07)
Male immigrants ≤ 10(≥60y)	42.30 (10.88)	41.43 (11.78)	41.03 (12.71)	40.61 (13.70)	40.17 (14.75)	39.71 (15.85)	39.24 (16.99)	38.75 (18.16)	38.23 (19.35)	37.71 (20.57)
Male locals(≥60y)	23.04 (3.29)	22.69 (3.56)	22.37(4.07)	22.16(4.84)	21.89 (5.86)	21.61 (7.22)	21.52 (9.02)	21.74 (11.29)	22.17 (14.03)	22.73 (17.28)

eTable 5. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of stomach cancer per 100,000 population for each gender, age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Predictive mean of age-standardized mortality rates of prostate cancer per 100,000 population										
Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Male immigrants >10	14.81 (0.61)	14.59 (0.79)	14.57 (0.96)	14.56 (1.15)	14.54 (1.37)	14.51 (1.61)	14.48 (1.86)	14.45 (2.13)	14.42 (2.42)	14.38 (2.72)
Male immigrants ≤10	9.03 (2.95)	8.78 (3.11)	8.58 (3.29)	8.39 (3.49)	8.19(3.69)	8.10(3.89)	7.82(4.11)	7.63(4.31)	7.45(4.51)	7.27(4.72)
Male locals	9.54 (1.40)	9.66 (1.57)	9.67 (1.66)	9.69 (1.77)	9.72(1.91)	9.75(2.06)	9.78(2.23)	9.82(2.43)	9.86(2.64)	9.9(2.88)
Male immigrants >10(<60y)	0.57 (0.12)	0.52 (0.17)	0.51 (0.19)	0.50 (0.21)	0.49(0.22)	0.48(0.24)	0.47(0.25)	0.46(0.27)	0.45(0.29)	0.44(0.31)
Male immigrants ≤ 10(<60y)	0.65 (0.59)	0.73 (0.77)	0.81 (0.93)	0.87 (1.10)	0.94(1.31)	1.01(1.51)	1.09(1.75)	1.16(2.02)	1.24(2.32)	1.33(2.64)
Male locals(<60y)	0.63 (0.12)	0.66 (0.14)	0.66 (0.16)	0.66 (0.19)	0.67(0.21)	0.67(0.24)	0.67(0.27)	0.68(0.31)	0.68(0.33)	0.69(0.37)
Male immigrants >10(≥ 60y)	49.43 (2.59)	49.61 (2.73)	49.63 (3.29)	49.64 (3.94)	49.64 (4.68)	49.64 (5.51)	49.63 (6.38)	49.62 (7.32)	49.61 (8.32)	49.58(9.37)
Male immigrants ≤ 10(≥60y)	28.29 (9.15)	27.66 (9.78)	26.53 (10.21)	25.4 (10.63)	24.28 (11.03)	23.16 (11.41)	22.07 (11.76)	21.01 (12.09)	19.96 (12.38)	18.95(12.63)
Male locals(≥60y)	31.57 (5.17)	31.48 (5.49)	31.40 (5.76)	31.32 (6.09)	31.24 (6.48)	31.15 (6.94)	31.06 (7.44)	30.96 (8.01)	30.86 (8.61)	30.74(9.26)

eTable 6. Predictive means and standard deviations (in brackets) of age-standardized mortality rates of prostate cancer per 100,000 population for each age group (less than, greater or equal to 60 years old) and immigrant status from 2022 to 2030. Reported means and standard deviations (in brackets) of age-standardized mortality rates in 2021 are also listed.

Reporting checklist for cohort study.

Based on the STROBE cohort guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cohortreporting guidelines, and cite them as:

von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.

		Reporting Item	Page Number
Title and abstract			
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	#3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	#4	Present key elements of study design early in the paper	5
Setting	#5	Describe the setting, locations, and relevant dates, including periods	5

		of recruitment, exposure, follow-up, and data collection	
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up.	5
Eligibility criteria	#6b	For matched studies, give matching criteria and number of exposed and unexposed	n/a
Variables	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	5
Bias	#9	Describe any efforts to address potential sources of bias	5
Study size	#10	Explain how the study size was arrived at	5
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	5
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	5
Statistical methods	#12b	Describe any methods used to examine subgroups and interactions	5
Statistical methods	#12c	Explain how missing data were addressed	5
Statistical methods	#12d	If applicable, explain how loss to follow-up was addressed	n/a
Statistical methods	#12e	Describe any sensitivity analyses	n/a
Results			
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible,	n/a

		included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	
Participants	#13b	Give reasons for non-participation at each stage	5
Participants	#13c	Consider use of a flow diagram	
n/a			
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	5
Descriptive data	#14b	Indicate number of participants with missing data for each variable of interest	
n/a			
Descriptive data	#14c	Summarise follow-up time (eg, average and total amount)	
n/a			
Outcome data	#15	Report numbers of outcome events or summary measures over time. Give information separately for exposed and unexposed groups if applicable.	
n/a			
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	6
Main results	#16b	Report category boundaries when continuous variables were categorized	n/a
Main results	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
n/a			
Other analyses	#17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	7

Discussion

Key results	#18	Summarise key results with reference to study objectives	8
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	10
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	8
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9
Other Information			
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	11

This checklist was completed on 11. February 2023 using https://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai